An empirical investigation of text-speak processing: Does cost outweigh the benefit?

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James R. Head

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CHAPTER 1

As the popularity of digitally based communication devices increases, so does the propensity for individuals to find clever ways to convey messages in a shorter amount of space and time. Often, individuals use word or phrase shortening techniques known collectively as text-speak. A majority of investigations into the topic of text-speak have only focused on the potential impact text-speak may have on literacy or scholastic achievement (Crystal, 2008; Pinker 1994; Thurlow, 2003). However, there is a void in empirical investigation into how individuals create text-speak and more importantly how they process it (Farrell & Lyddy, 2012). The primary aim of this dissertation is to systematically investigate text-speak using various methodological techniques to gain a better understanding of how people create text-speak and explore how it elicits meaningful comprehension. An additional aim of this dissertation is to determine whether processing text-speak comes at a cognitive cost.

1.1 Brief history of text-speak and contemporary use

The art of shortening words or phrases symbolically (i.e., brachygraphy) dates back to Roman antiquity (Delano, 1997). During this time, scribes would take diligent notes of speeches or debates for the purpose of keeping records. These notes were usually taken on wax tablets that were small in size and had limited space for writing. Thus, scribes adopted the use of brachygraphy to transcribe notes in a shorter amount of space and arguably time. Although there have been considerable advancements in technology, shortening words or phrases is still currently utilized in online instant messaging, emailing, and text-messaging (Crystal, 2008). Although text-speak uses symbolic notation (e.g., heart, **<3**), it has been extended to include various other shortening techniques. For example, subsets (group, **grp**), shortcuts (tonight, **2nite**), numerals (too, **2**), and s (laugh out loud, **LOL**) (see Kul, 2007, for further examples). As stated above, text-speak permits an individual to convey messages in a smaller amount of space and arguably shorter amount of time (Crystal, 2008; Head, Helton, Russell, & Neumann, 2012).

Short Message Service (SMS), more commonly known as “text messaging”, was originally intended for cell phone companies to communicate with customers (Agar, 2003; Wray, 2002). In the past decade, however, text messaging has become an increasingly preferred mode of communication, most notably among young adolescents (Madell & Muncer, 2004; Tagliamonte & Denis, 2008). Although New Zealand is a small country with around 4.3 million people, it has approximately 4.6 million mobile phone subscribers, which can be attributed to some people owning more than one phone (CIA, 2009). On average over a million text messages are sent daily within New Zealand (Bramley et al., 2005). This popularity of text messaging is mirrored worldwide (Lenhart, Ling, Campbell, & Purcell, 2010; Rheingold, 2002).

Communication mediums such as text messaging and Twitter limit the space available to communicate a message. For example, mobile phone service providers generally limit a text message to 160 characters (i.e., letters and spaces) per message (Berger & Coch, 2010), while Twitter limits messages to 140 characters (Twitter, 2012). Limited space has prompted users of these communication mediums to use shortening techniques such as text-speak (e.g., great to see you, **gr8 2 cya**). However, it should be noted that limited space is not the single catalyst prompting the use of text-speak. Text-speak has also been noted in other communication mediums where relative space is not as limited, such as blogs, forums and community social networks (e.g., Facebook and MySpace), and emailing (Crystal, 2008; Drounin & Davis, 2009). The vast majority of research on text-speak to date has focused on the detrimental effects text-speak has on literacy. Critics of text-speak have argued that it is counterproductive to language production for students (Thurlow, 2006; Sutherland, 2002;

Ihnatko, 1997), while others have argued that text-speak has no negative effects (Crystal, 2008; Drouin & Davis, 2009; Kul, 2007). This specific concern has surfaced within New Zealand. The concern arose when examination markers penalized students for using text-speak in formal examinations by awarding them lower scores. Controversially, the New Zealand Qualifications Authority (NZQA) moved to allow students to use text-speak in formal exams due to its widespread use and appearance in examinations. The NZQA's argument was that regardless of whether text-speak was used, if the student shows the required knowledge of a subject, then they should be given credit. As expected this was met with anger from educators; for example, one school principal stated, "permitting text abbreviations in the National Certificate of Educational Achievement exams made a joke of the teaching of proper grammar" (Smith, 2006).

1.2 Why investigate text-speak?

As outlined above, the use of digitally based communication is pervasive and is likely to increase with further advancements in technology. Further use of digitally based communication by individuals is likely to dramatically increase as prices for communication devices decrease and availability increases. This presents a potential problem in that more individuals may use digital based communication such as text-messaging or emailing with their phone while completing another task (e.g., driving). Similar to driving while talking on a cell phone, communicating with digitally written communication can be dangerous.

It seems to be a common occurrence in the news that accidents in the workplace have been associated with text messaging. For example, a Metrolink passenger train conductor who was texting caused a major accident when failing to see a stop signal, which resulted in the train colliding with another train causing 25 deaths and 135 injured (Elsworth, 2008). The accident was attributed to the divided attention of the train conductor who was reading and responding to text-messages and failed to see a critical signal (stop signal). In another incident, a bus driver was momentarily reading a text-message and had to swerve the bus into a guard rail to avoid hitting a motorcyclist, thereby causing injuries to passengers (Carvajal, 2012). Passengers on the bus reported that the driver was constantly text-messaging, which caused him to fail to notice the motorcyclist in his lane.

Numerous car accidents have been attributed to the use of text-messaging while driving (Lee, 2007). Indeed, an associate of the author of this dissertation severely damaged their vehicle and almost lost their life while reading and responding to text-messages containing text-speak. When I give presentations on the dangers of texting, I often show the pictures depicted in Figure 1.1.

Figure 1.1. Pictures depicting damage done to a vehicle as a result of reading a text.

Unsurprisingly, when I ask the audience, “what caused this accident?” the answers are generally, “driving under the influence of drugs or alcohol”, and “sleeping”. Rarely does anyone guess that the owner of the vehicle momentarily took their eyes of the road for only seconds to read a text-message while driving 85 mph (136 km/h). The divided attention between driving and text-messaging resulted in the car drifting onto the shoulder of the road which was composed of loose dirt. The owner of the vehicle over corrected the steering and rolled until the car was impaled by a large metal rod that went through the driver's side door and almost killed the driver. Although it is common knowledge that texting while driving is dangerous, it is still pervasively done. Indeed, driving while texting has become so problematic that government legislation has outlawed texting while driving in New Zealand (NZTA, 2012). Interestingly, this danger has also occurred off the road. Recently, in fact, a pilot was killed while flying his personal airplane while text-messaging (Sunde, 2012). Data collected after the crash revealed that during the flight the pilot's altitude would abnormally fluctuate when receiving and sending text-messages. Safety officials attributed the dangerous altitude fluctuations as being due to the divided attention of the pilot reading text-messages while operating the plane.

Undoubtedly, texting while operating any vehicle is dangerous for a multitude of reasons. Firstly, drivers are momentarily taking their eyes off the road and vehicle instruments which could lead to missed critical events (e.g., vehicles or critical alert). Secondly, the driver has to remove a hand(s) and engage fine finger movement and coordination to convey a message. Thirdly, the driver has to read and comprehend written content and convey a message back. Texting is not only demanding of motor and visual processing, but also higher order cognitive processing involved in reading and writing a message. However, what is not clear is if the content (e.g., text-speak) of the text-message can further compound error by demanding more attention than normal text. Because text-speak is likely not as easy to read for comprehension, it could potentially pose a problem by further dividing a person's attention which could exacerbate dangerous errors while operating a vehicle. Text-speak not only has the potential to be dangerous while operating a vehicle, but also in workplaces. Surprisingly, an environment that commonly uses shortening techniques (i.e., text-speak) is in hospitals. For example, due to limited time and a high number of patients medical practitioners commonly use abbreviations to shorten messages such as for diagnosis and prescriptions to save time and limited space on lengthy forms. Unfortunately, due to non-standardization, medical practitioners commonly misinterpret such messages containing abbreviations which can lead to deadly consequences due to incorrect amount or type of medication prescribed (Margolin, 2006; Turkoski, 2009). This problem could become even more likely for medical practitioners using Health Information Technology (HIT), whereby medical history is corrected electronically. Indeed, HIT-based systems are commonly used by New Zealand doctors (Janals, Day, & Orr, 2013), and will likely be used widely in the United States due to changing policy under the Obamacare HIT requirement.

The use of digitally based communication which could include text-speak is not only a civilian problem but also potentially a military one. This is especially concerning as modern militaries begin to shift from older technologies (e.g., radio communication) to more advanced Multi-Modal communication where messages can be received vocally and written via chat room discussions (Finomore, Popik, Castle, & Dallman, 2010). These new communication technologies allow militaries to shift to a network-centric operations doctrine whereby flow of information between military personnel is more easily accessible and recordable allowing for greater situation awareness and the added benefit for information to be reviewed later. Arguably, those using this technology in the theatre of battle will likely have limited time to communicate, which could encourage the use of shortening techniques to communicate in a truncated amount of time. This could be potentially disastrous if the person reading the message is not familiar with text-speak abbreviations.

As communication technology evolves so does the likelihood for someone to encounter text-speak. The anecdotes above provide evidence that the act of digital based communication, while concurrently completing another task, may cause performance impairments which could result in dangerous consequences (e.g., operating a vehicle). Additionally, reading text-speak could be susceptible to misinterpretations which could result in further division of attention, and potentially deadly consequences. The lack of understanding of text-speak processing has implications not only in the workplace, be it civilian or military, but also for individuals who use is it while operating a vehicle. It is therefore imperative to systematically investigate text-speak to determine how people create it and, more importantly, whether there is an associated cognitive cost to process it.

1.3 Overview of this dissertation

The format of this dissertation varies from convention, as the majority of chapters are based on separate, self-contained, journal articles or proceedings that have been published or are in press. The subsequent chapters contain six self-contained studies, each with its own literature review, findings, and conclusions. Therefore, some repetition was unfortunately unavoidable. The norming study and text-speak questionnaire developed in Chapter 2 involves the creation of a New Zealand text-speak word norm database, and text-speak experience questionnaire. The development of the normed text-speak stimuli and text questionnaire were imperative for controlling experimental stimuli and gauging participants experience with text-speak. Chapter 3 explores whether a specific form of text-speak (i.e., subsetting), which is the removal of letters (e.g., vowels or consonants) from a word, has lexical representation by using an unconscious masked priming paradigm. Chapter 4 contains two experiments that address the cognitive demands of text-speak and how performance is influenced by individual differences in text-speak experience, while also investigating an empirical debate on the sustained attention to response task. In Chapter 5, to further explore the cognitive demands of text-speak, a dual-task paradigm was used whereby participants read a story presented in text-speak or correctly spelled words while concurrently responding to a secondary vibration detection task. In Chapter 6, I investigate how people utilize sentence context and respond to correctly spelled or text-speak target probes presented in a divided visual field paradigm to determine the role of the left and right hemisphere when processing text-speak versus correctly spelled target probes. In Chapter 7, cerebral oxygenation in the right and left prefrontal cortex is measured while participants read sentences composed of text-speak or correctly spelled words in order to quantify physiological changes in the prefrontal cortex as a result of reading text-speak. Finally, Chapter 8 includes a brief conclusion, summarising the highlights of all the studies, and addresses application issues regarding the findings, as well as suggestions for future research with text-speak.

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Head, J., Helton, W. S., Russell, P., Neumann, E. (2012). Text-speak processing impairs tactile location. *Acta Psychologica, 141*(1), 48-53.

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Head, J., Helton, W. S., Neumann, E., Russell, P., & Shears, C. (2011). Text-speak Processing. *Proceedings of the Human Factors and Ergonomics Society, 55*(1), 470-474.

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Head, J., Wilson, K., Helton, W. S., Neumann, E., Russell, P., & Shears, C. (2013). Right Hemisphere prefrontal cortical involvement in Text-speak. *Proceedings of the Human Factors and Ergonomics Society.*

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CHAPTER 2

Development of a text-speak questionnaire[1]

2.1 Abstract

Prior investigations on text-speak have failed to use a standardized text-speak questionnaire to determine participants experience and attitude towards text-speak. Therefore, a short questionnaire was created to assess participants experience and attitude with text-speak. First, 10 participants were recruited to participate in structured interviews to aid in the creation of 11 text-speak questionnaire items. An additional six participants were recruited as text-speak experts to assess content validity of the 11 text-speak questionnaire items generated in the structured interview. As a result, two items were eliminated and three items were reworded based on feedback from text-speak experts. The final questionnaire consisted of eight Likert scale items and one open ended question. Finally, 1,182 participants were recruited and asked to respond to the 9-item text-speak questionnaire. A principle component factor analysis was used and resulted in a 3-factor solution: Factor 1 willingness to use text-speak word/phrase representation, Factor 2 represents overall text messaging experience, and Factor 3 represents preference for using text messaging.

[1] Based on a published preliminary study: Head, J., Helton, W. S., Neumann, E., Russell, P., & Shears, C. (2011). Text-Speak processing. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 55*(1), 470-474.

2.2 Introduction

The role of individual differences has been noted to influence the way people approach and perform tasks. For example, people who engage in deliberate practice are more likely to have improved performance compared to those who do not. (Ericsson, Krampe, & Tesch-Rmer, 1993). Arguably, this same principle can be applied to people's processing of text-speak. Similar to someone repetitively practicing a sport, a person who reads and uses text-speak often is likely to read and comprehend text messages more proficiently.

To the author's knowledge, from reviewing the literature on text-speak, no standardized questionnaire has been constructed that could measure differences between people in their experience with text-speak. Indeed, previous investigations involving text-speak have used a single item questionnaire that was adapted from one originally designed for classifying monosyllabic words (Balota, Pilotti, & Cortese, 2001). The single item questionnaire is given post task and lists each text-speak item followed by a 7-point Likert scale that identifies how often the person has read the text-speak item; for example, "1 = never, 2 = once a year, 3 = once a month, 4 = once a week, 5 = every 2 days, 6 = once a day, 7 = several times a day"(Ganushchak, Krott, Frisson, & Meyer, 2011; Ganushchak, Krott, & Meyer, 2010a, 2010b; Ganushchak, Krott, & Meyer, 2011). Although the single item questionnaire is potentially useful it may lack predictive validity and fail to predict behavioural or physiological performance with text-speak. This is likely due to the single item questionnaire being unidimensional, which may fail to adequately asses other latent characteristics that explain text-speak experience.

The goal of this chapter was to create a short and relatively easy to interpret questionnaire that could be used in future studies or work environments where text-speak may occur. To achieve this goal, I created and distributed a text-speak questionnaire to a large number of students at the University of Canterbury. A large number was needed to allow a principle component factor analysis of the inter-item correlations. A principle component factor analysis was conducted for two reasons. First, it was anticipated that there would be high inter-item correlations, thus the use of a dimensional reduction technique was warranted (Tabachnick & Fiddell, 2007). Secondly, reducing the number of items into fewer meaningful factors would make use and interpretation of the questionnaire easier. No a priori hypotheses were used with regards to factors.

2.3 Method

Item generation phase. Ten participants (5 males) from the University of Canterbury participated in structured interviews. Their ages ranged from 18 to 30 years (M = 26.9; SD = 11.69). Participants were asked to discuss their thoughts and experiences with text-speak to generate motifs. Those that had experience with text-speak were requested to elaborate on what type of text-speak they encountered. The first motif was valence with participants either expressing disdain towards text-speak or being highly accepting of it. The second motif concerned the extent to which experience with text-speak had occurred in the context of text-messaging. The third motif was the affordance that text-speak provided. The final motif was type of text-speak commonly used and this focused on removal of letters from words or the use of s. These motifs were used to generate a preliminary list of 11 items.

Generally, the next step in a scale construction is to find experts that can evaluate items for content validity (DeVellis, 2012). Therefore, an additional 6 (4 female) participants (age: M = 24; SD = 4.05) were recruited as subject matter experts (SMEs). These participants were recruited from those that participated in the word norm study discussed in Chapter 3. Selection of SMEs was accomplished by rank ordering native English speaking New Zealanders who completed the text-speak word norms study based on the frequency of use of text-speak representations. These participants were later contacted and requested to inspect questionnaire items for content validity and ease of comprehension. SMEs were instructed to read and screen text-speak questionnaire items for ease of comprehension and content validity. This resulted in 2 items being removed and 3 items being reworded. The final questionnaire resulted in eight 7-point Likert scale items and one open ended question. The 7-point Likert scale was chosen because it is considered more sensitive than other standard lengths (e.g., 5-point) (Jaeschke, Singer, & Guyatte, 1989). The final items are presented in Table 2.1

Table 2.1

Example of questionnaire items used in study

Q1) I text message very often
Q2) I always use acrostics (got to go-gtg) when text messaging
Q3) I always use subsetting (Text-Txt) when I send text messages
Q4) I always use predictive text when I use my cell phone
Q5) I find it easier to text message than placing a call
Q6) I find it faster to communicate by text messaging than by placing a call
Q7) When someone sends me a text with words missing letters, I can understand what they are trying to say by the context of the message
Q8) I get annoyed when people use methods to shorten words or phrases
Q9) What is the number of texts you send a day?

Participants. One thousand one hundred and eighty-two University of Canterbury students (826 women and 256 men) participated in the study in exchange for course credit. A large number of participants were selected as recommended for factor analysis (Comrey & Lee, 1992). Data from ten participants were excluded because they did not follow instructions for completing the questionnaire. Additionally, five participants were removed because they weree not native to New Zealand. All participants were native English speakers and native New Zealanders with a mean age of 20.62, $SD = 5.29$, and had normal or corrected to normal vision.

Procedure. Participants were instructed to read each scale item and respond as accurately as possible. Participants were instructed to not spend too long on any item. Presentation of the questionnaire was accomplished using E-prime 2.0 (Schneider, Eschman, & Zuccolotto, 2002).

2.4 Results

Descriptive statistics of the 9-items of the text-speak questionnaire were inspected for non-normality and reverse scored when necessary (items 4 and 8). A Z-score transformation was done prior to analysis to accommodate question 9, which was open ended. (see Table 2.1). The items were subjected to a principal component analysis (PCA) using SPSS version 19. Prior to analysis, the data were checked for suitability in a PCA. Inspection of the correlation matrix revealed that many of the correlation were .30 and greater. The Kaiser-Meyer-Olkin value was .60 which is adequate (Kaiser, 1970), and the Barlett's Test of Sphericity (Barlett, 1954) reached statistical significance ($p < .001$). Collectively these results supported the factorability of the correlation matrix.

A factor analysis (principle component analysis) with a Varimax rotation was performed. Varimax rotation was chosen to maximize high and low correlations between factors. We used an Eigen values greater than 1 criterion to determine the number of factors. This resulted in a three factor solution accounting for 57 % of the variance. Using Cattell's (1966) Scree test, it was decided to retain three components for further investigation. However, because the Scree test and Kaiser-Meyer-Olkin method have been criticized for overestimation of the number of components (Hubbard & Allen, 1987; Zwick & Velicer, 1986); a Parallel Analysis (Watkins, 2000) was also performed. A Parallel Analysis involves the comparison of Eigen values derived from SPSS and comparing these to Eigen values created from a randomly generated sample using Monte Carlo methods (Metropolis & Ulma, 1949). Eigen values in SPSS that are greater than those generated in the random sample are retained. The three factor solution derived in the Varimax and Scree test were supported by the Parallel Analysis (see Table 2.2), which showed the same three components with Eigen values exceeding the corresponding criterion values for a randomly generated data matrix of the same size (9 variables x 1080). The loadings from the factor pattern matrices for the scale items are reported in Table 2.3. Loadings greater than 0.40 are shown in bold.

Table 2.2

Results of the Parallel Analysis for the 3 factor solution

Component	Sample	SPSS	Decision
1	**1.1342**	**2.189**	**Accept**
2	**1.0896**	**1.721**	**Accept**
3	**1.057**	**1.22**	**Accept**
4	1.0281	0.958	Reject
5	0.9991	0.845	Reject
6	0.97	0.761	Reject
7	0.9406	0.653	Reject
8	0.9096	0.336	Reject
9	0.8717	0.315	Reject

Note. Bolded items reflect accepted components

Interpretation and naming of factors. After factor loadings were determined, each factor's items were inspected and meaningful and logical interpretations were used to devise descriptions (Tabachnick & Fidell, 2007). For factor 1 items 2, 3, 4, and 8 collectively capture a willingness to use text-speak word/phrase representation. Factor 2 which consisted of items 5 and 6 measured the perceived affordance that text speak provides which reflects preference for using text messaging, and Factor 3 consisting of items 1 and 9 represented overall text messaging experience.

Table 2.3

Factor loadings for each item on the text-speak questionnaire

Variable	Factor 1	Factor 2	Factor 3
Q1.	.128	.194	**.730**
Q2.	**.835**	.113	.101
Q3.	**.811**	.098	.097
Q4.	**.424**	.070	-.391
Q5.	.010	**.905**	.040
Q6.	.054	**.904**	.068
Q7.	.365	-.045	.308
Q8.	**.620**	-.101	-.208
Q9.	-.076	-.004	**.702**

Bolded items have a loading of .40 or greater

2.5 Discussion

A text-speak questionnaire was created with the aim of providing a tool capable of measuring differences between people in their experience with text-messaging and more specifically with text-speak. The results supported a three factor solution: Factor 1 represents willingness to use text-speak word/phrase representations; Factor 2 represents preference for using text messaging; and Factor 3 represents overall text messaging experience.

Arguably, a person who has more experience with a task will exhibit more competent performance compared to those with less experience (Ericsson, Krampe, & Tesch-Rmer, 1993). The same could likely be said for experience with text-speak. Those who have more experience with text-speak are more likely to extrapolate meaning from a text-speak message.

Previous investigations on the topic of text-speak processing have failed to adequately address possible differences between people in experience or familiarity with text-speak. Therefore, the goal of the current investigation was to construct a questionnaire that could measure differences in experience with text-speak experience.

To achieve the goal of creating a text-speak questionnaire, structured interviews were conducted to obtain motifs which were used to create text-speak items. This resulted in the creation of 11 items. The 11 items were further reduced to 9 items after 6 SMEs inspected the items for content validity and ease comprehension. Finally, the questionnaire was tested with a large number of undergraduate students which provided sufficient power to conduct a factor analysis. A principle component factor analysis resulted in isolation of factors for willingness to use, experience, and preference for text-speak.

A limitation should be noted with concern to the text-speak questionnaire. Although the sample size was adequate, it lacked proper representation of the New Zealand population. The majority of the participants that provided data for the questionnaire were young undergraduate university students. Although this was primarily done because future studies that will be later discussed in the dissertation would primarily involve the recruitment of students from the university. This is potentially problematic in that it does not take an older adult population into account. Future studies with the text-speak questionnaire should certainly consider expanding the age range to include an older population to cross validate the questionnaire. This would enable the use of the questionnaire to a wider population demographic.

Summary and Conclusion. In Chapter 2, a study was conducted to create a short questionnaire that could be used to measure differences between people in their experience with text-speak. A principle component factor analysis revealed a 3 factor solution. However, the predictive validity of the questionnaire has not been established. Therefore, in the next chapter, the text-speak questionnaire is administered with a behavioural experiment to determine whether it has any predictive validity with regard to participants' performance on a task.

CHAPTER 3

Study 1

New Zealand text-speak word norms and masked priming[2]

3.1 Abstract

Text messaging and online instant messaging are popular means of communication in New Zealand. Given the constraints of space and time, people use text-speak a (method for shortening words or phrases) to convey messages more concisely (Head, Helton, Neumann, Russell, & Shears, 2011). The current study collected text-speak word norms from 100 native New Zealanders. An abridged sample of these subset text-speak words (e.g., txt, text) was used within a masked priming experiment. It was found that subset primes produce significantly faster and more accurate responses to target probes relative to non-words in a lexical decision task. A 9-item text-speak questionnaire was given to determine if a relationship between subset priming and experience with text-speak exists. The questionnaire revealed that those who reported being more experienced with text-speak benefited more from text-speak primes than those who reported being less experienced. Overall the result supports an Interactive Activation account of word processing (McClelland & Rumelhart, 1981).

[2] Published paper: Head, J., Neumann, E., Russell, P., Helton, W. S., Shears, C. New Zealand text-speak word norms and masked priming effects. *New Zealand Journal of Psychology,42*(2), 5-16.

3.2 Introduction

The use and processing of text-speak can be understood from a cost-benefit perspective. The use of text-speak provides the user with the benefit of shortening a message to convey it more quickly and in less space. However, this benefit for the writer comes at a cost for the reader of the message. The reader of a text-speak message has to extract meaning from a compressed and unfamiliar symbol combinations, which results in a processing cost resulting in increased error rates and greater comprehension times (see Head, Helton, Russell, & Neumann, 2012). Various studies have recently begun to examine the cognitive costs of processing text-speak.

Eye tracking studies have shown that when someone is reading text-speak, their eyes fixate longer on text-speak items. Additionally, readers of text-speak have reduced reading speed when trying to comprehend sentences composed of text-speak comparatively to sentences composed of correctly spelled words (Ganushchak, Krott, Frisson, & Meyer, 2011; Perea, Acha, & Carreiras, 2009). Longer fixations and reduced reading speed are indicative of increased cognitive demand placed on the reader (Reilly & Radach, 2006; Salvucci, 2001). This increased demand may in part arise because text-speak abbreviations do not have the same level of automatic activation as correctly spelled words. Meaning is generally considered to be extracted automatically from correctly spelled words which also capture the attention of readers, (Johnson et al., 1990; Stroop, 1935); however, the same cannot be said for text-speak. Head, Russell, Dorahy, Neumann, and Helton (2011), for example, presented participants with correctly spelled words and subsets within a sustained attention task. Rare target words presented in text-speak were responded to more slowly and were more difficult to detect than correctly spelled words. Moreover, participants who reported having less experience using text-speak were less accurate and took longer to detect text-speak targets than those reporting greater experience in the use of text-speak.

Conscious priming experiments have shown that although text-speak possesses lexical representations (Ganushchak, Krott, & Meyer, 2010); they are more difficult to incorporate semantically within an otherwise correctly spelled sentence (Head, Shears, Helton, & Neumann, 2013). Reading sentences composed of correctly spelled words can arguably lead to automatic top-down conscious spreading activation of words and the concepts they entail (Balota, 1983; Neely, 1977). Text-speak, coupled with correctly spelled words, may provide the reader with enough context to facilitate correctly spelled word activation for text-speak word representations. Thus, context contamination, may make it difficult to determine whether text-speak words isolated from context have semantic meaning in their own right.

One prominent method of avoiding the influence of sentence context on words is the masked priming technique (Berent & Perfetti, 1995; Dehaene et al., 1998; Forster & Davis, 1984, Forster & Davis, 1991; Grainger & Segui, 1990; Perea & Gomez, 2010; Perea & Gotor, 1997). This technique comprises a very brief presentation of a prime stimulus (typically 30-50 ms) followed immediately by either a short duration post mask or a more enduring probe stimulus, which both serve to terminate the effective visibility of the prime. Commonly participants are required to make word/non-word decisions (lexical decisions) to probe stimuli. Interest focuses on the effects of the prime on probe lexical decision times. Since the goals of research relate to the extraction of meaning from the primes, prime and probe stimuli are frequently presented in different cases (uppercase and lowercase) to exclude physical identity as an explanation of priming effects. The major advantage of masked priming techniques is that they permit the investigator to examine lexical priming in the absence of conscious awareness of the primes (see, e.g., Bodner & Masson, 2003; Bourassa & Besner, 1998; Perea & Gomez, 2010; Perea & Gotor, 1997; Perea & Lupker, 2003).

The masked priming technique has already been used with text-speak words and has generated reliable priming effects (Head, Helton, Neumann, Russell, & Shears, 2011). Head, Helton, Neumann et al. (2011) were able to show that subset text-speak words (e.g., **TXT**, text) may possess lexical meaning. Participants within a masked priming experiment responded faster and more accurately to target words preceded by subset primes (**TXT,** text) relative to non-word primes (**YFT,** text). Additionally, subset prime words produced only marginally less accurate and slower responses than correctly spelled words in the identity condition (**TEXT,** text). Although the results are compelling, some caution is warranted regarding whether lexical processing for masked subset primes did occur. Specifically, many upper- and lower-case words share the same grapheme features (e.g., Cc, Kk, Mm, Oo, Uu, Xx). Thus, it is possible that participants were subconsciously benefitting from feature matching instead of lexical representation when making lexical decisions.

Although more than a few decades old, the Interactive Activation Model (IA) is still pertinent when making interpretations of masked priming results (Grainger & Jacobs, 1996; Massol, Grainger, Dufau, & Holcomb, 2010; McClelland & Rumelhart, 1981). The IA is essentially a connectionist model of word processing that involves separate yet concurrent processing systems working together to achieve word level activation. Within this model, perceptual processing (i.e., bottom-up) takes place at different levels that are interconnected. Each level has a responsibility for processing different perceptual information (e.g., feature, acoustic, phonetic and letter) and are interconnected by excitatory and inhibitory connections.

Collectively, perceptual processing levels work together to take raw perceptual information that ultimately contributes to letter and word level activation. This bottom-up processing is multitudinous in the sense that various other words are simultaneously receiving excitatory or inhibitory activation from peripheral and word-level processing. A single word is ultimately selected based on receiving enough excitatory activation to exceed a threshold relative to other competing words.

McClelland and Rumelhart (1981) argue that the driving force behind masked priming is due to a prime word being selected and activated by exceeding a threshold. Once the prime disappears there is still residual activation for that word. Thus, when a target word appears and is identical to the prime, it will require less excitatory activation to make a “yes” response in the lexical decision. This residual excitation from the prime to probe is what enables priming effects (i.e., increased accuracy and speeded responses).

Crucial to the IA model is the contribution of a higher level input (i.e., top-down) source that also contributes to word level activation. McClelland and Rumelhart (1981) suggest that prior knowledge of a language and words can have similar excitatory and inhibitory effects at the word level. Thus, for example, an individual learning a new foreign language would likely have less excitatory influence from the top-down level processor to a new foreign language. However, as an individual becomes more accustomed to the foreign language, the top-down processor would likely exhibit increased excitatory influence.

Although text-speak is not by definition a foreign language per se, it does differ perceptually in appearance and uses different spelling rules relative to conventional English spelling (e.g., Gr8 2cya ystrdy!, Great to see you yesterday!). For someone who is not literate with text-speak, the sentence above could be extremely difficult to decipher. However, if the same sentence is presented to an individual who is experienced with text-speak, then the sentence might be read as easily as its correctly spelled analogue. Therefore, if the IA account of top-down experience is valid, then those who are more experienced with text-speak should have greater priming effects when shown a text-speak prime relative to those who are less experienced with text-speak. In the current investigation, the IA model is tested to determine whether top-down experience with text-speak influences text-speak processing.

An extensive literature search has not revealed a published text-speak word norm stimuli list and specifically not one for New Zealand. Although some anecdotal text-speak websites exist (e.g., www.lingo2word.com), their data collection and actual results are questionable. Additionally, these types of websites do not take regional colloquialisms into consideration. In other words, native New Zealanders may use different text-speak representations than natives of the USA or Canada. Thus, because we believe that text-speak processing is a fertile venue for future studies; it is useful to provide objective New Zealand text-speak word norms for future investigations. Additionally, it was of interest to empirically investigate a specific form of text-speak (i.e., subset) processing using these acquired norms in a masked priming experiment.

The present experiment was designed to provide further corroboration that subset text-speak items can convey meaning in the absence of top-down and contextual influences. Additionally, we wanted to address some issues raised in Head, Helton et al. (2011). First, to address concerns that grapheme feature overlap was possibly driving the priming effects reported. To address this, a font change condition in which the *prime* was presented in Bell MT italicised and the target probe in Courier font (e.g., *FINALLY*-`finally`). Second, Head, Helton et al., failed to show significant correlations of age and sex with priming magnitude. Indeed, it has been noted that young adolescents use text-speak more than adults (Crystal, 2008). The absence of significant correlations between age and magnitude in Head, Helton, et al. may in part have been due to the small sample size used in the correlation (n = 87). Thus, to increase statistical power, we significantly increased the sample size of the current study (N = 416). In the current investigation we predict that younger individuals will have greater experience with text-speak and thus will benefit more from the text-speak prime than older individuals. Previously research has shown that mass practice can improve performance and increase expertise on a task (Fitts & Posner, 1967; Gibson, 1969). To further explore expertise and text-speak processing we wanted to examine whether a relationship exists between the numbers of text messages sent per day and priming magnitude. Finally, based on the IA model and the influence of top-down level of experience, we predicted that those who reported sending more messages per day are likely to be more exposed to text-speak and thus will benefit more from subset primes than people who send fewer text messages.

3.3 Study 1

3.4 Method

Participants. One hundred University of Canterbury students (71 women and 29 men) participated in the study in exchange for course credit. All participants were native English speakers and native New Zealanders with a mean age of 20; *SD* = 5.14, and had normal or corrected to normal vision.

Word stimuli. A selection of 1,193 words was selected from the Chiarello, Shears, and Lund word norms (1999). These words were pure nouns, pure verbs, or noun verb combinations (e.g., watch). The mean letter count was 5.05 (range: 3-7). The stimuli were divided into four lists. Participants were randomly assigned 25 to each list.

Procedure. There were two parts to the norming task. First participants were shown correctly spelled words one at a time on a computer screen and asked to type shortened forms of the words that they would use when online and instant messaging, text-messaging, tweeting, blogging or emailing or to indicate if they would not shorten the word. Upon completion of the word task participants were requested to complete a free response task. Participants were asked to type text-speak representations that they used in their own messaging. The tasks were completed individually or in small groups in a quiet room. Before these tasks, participants were asked to read an overview of the tasks and requested to sign an informed consent. The norming task took approximately 30 minutes to complete.

3.5 Results

Text-speak word representations were aggregated based on the shortening techniques employed by the participant and if that representation had the same grapheme or symbol configuration as other participants. For example, all participants who shortened the word, "accept" as "acpt" were aggregated together and those who shortened phrases in the free responses portion such as "talk to you later" as "ttyl" were aggregated together. For each word or phrase we provided its equivalent text-speak form and the percentage who responded with that representation. Due to limited space, we have only included examples of stimuli used in this study (see Appendix A)[2].

3.6 Discussion

For the norming study, participants were presented with correctly spelled words and were instructed to create a text-speak version for each word. Participants were instructed to imagine they were online instant messaging, text-messaging, tweeting, blogging or emailing when creating their text-speak representations. Additionally, we also collected participants free response text-speak representations. This study was successful in creating a normed stimuli set for text-speak word and phrase representations for studies involving native New Zealanders.

3.7 Experiment

As described in the introduction, the goals of the present experiment were to explore a specific form of text-speak (i.e., subsets) and determine if these text-speak items have lexical meaning and whether experience with text-speak mediates priming effects. Additionally, to determine whether grapheme feature overlap was driving the priming effects found in Head, Helton et al. (2011). Thus, to achieve these goals, an abridged stimuli set was selected from the norming study discussed above consisting of subsets that were created by removing 1 or 2

[2] We have provided other subset word forms and free responses (e.g., phonetic respellings, shortcuts, acronyms, nonconve and numerals) not reported in this paper online for downloading: (https://docs.google.com/file/d/0B0juLcc2QNN4WkNU

letters from correctly spelled words. With the abridged stimuli set, we further degraded feature overlap between prime and probe by presenting the target and probe in different cases and different font types.

3.8 Methods

Participants. Four hundred and sixteen New Zealand University students (300 females) participated in the experiment in exchange for course credit. All were native speakers of English with a mean age of 20, *SD* = 5.0, and had normal or corrected-to-normal vision. Five participants were removed for not meeting language requirements.

Materials. An abridged stimulus set was selected from the norming study. In the experiment, a target word **(text)** could be preceded by a prime in the form of (1) an identical word (**TEXT**), (2) a non-word (**GRFP**), or (3) a subset (**TXT)**. Subset primes had either 1 or 2 letters omitted (e.g., west-wst, rubbish-rubsh, respectively). Identity primes, non-word primes, and subset primes with 1 or 2 letters omitted were rotated throughout the font change manipulation such that each prime condition appeared in the different font or same font condition and each target word only appeared once per list. The font change condition was treated as a between-subjects factor. Thus, half of the participants were assigned to the condition where the prime was presented in Bell MT font and the target in Courier font, while the other half of participants had both prime and target presented in Courier font. Eight stimuli lists were created to counterbalance between conditions across participants. Each list consisted of 280 items with equal numbers of word and non-word probes and targets. Subset words with a mean normative response greater than 20% were selected to serve as the primes in the subset prime condition. Subset words had a mean letter count of 3.75 (range: 3-5) and a mean normative response of 25% (range: 4%-64%). The target words had a mean letter count of 5.25 (range: 2-7). Similarly to Head, Helton et al., 2011, we presented the prime in uppercase and the target probe in lower case. Additionally, to further discourage grapheme overlap; we included a font change manipulation as a between subject factor. Half the participants were presented with primes and targets in Courier font while for the remainder primes were displayed in the Bell MT font and targets Courier font. All stimuli were presented in size 18 black fonts. To determine participants' familiarity with the Bell MT font, a familiarity scale was constructed. Participants' response were made on a 7-point Likert scale whereby 1 = "Not familiar" and 7 = "Very familiar". Overall familiarity with the Bell MT font was low ($M = 2.9$; $SD = 1.4$). Post-hoc analysis did not reveal any significant correlations with level of familiarity to font and priming effects.

Procedure. Participants were tested individually or in groups within individual cubicles. Participants were seated 50 cm in front of 37.5 x 30 cm Philips 220SW LCD screens. Presentation of stimuli and recordings of accuracy and reaction time were completed on PC computers using E-prime Professional 2.0 (Schneider, Eschmann, & Zuccolotto, 2002). On each trial a forward mask of hash marks (######) was presented for 500 ms followed immediately by the prime (see Head, Helton et al., 2011 Perea, Dunabeitia, & Carreras, 2008; Perea & Gomez, 2010 for similar procedures). The prime was presented in the same location as the hash marks and was presented in uppercase on the screen for 50 ms. Immediately after the prime a target probe was shown until a participant made a lexical decision response. Participants completed practice trials until they achieved at least 85% correct to proceed to the experimental trials. Responses were captured using a serial response mouse. Participants were instructed to make "word" responses (e.g. sweet) by using the index finger of their dominant hand to press the left button on a serial mouse and to indicate "non-word" targets (e.g. gsdge) by pressing the right button with the middle finger of the same hand (the mouse was rotated 180^{o} for left handed participants). Participants were not informed of the masked prime. No participants reported being able to perceive the masked primes at the conclusion of the study. Upon finishing the experiment, participants completed a text-speak questionnaire that assessed demographics, frequency of text use, and text-speak experience as discussed in (Chapter 2). The experiment duration was approximately 20 minutes.

3.9 Results

Reaction times greater than 1,500 ms and less than 250 ms (less than 1% of the data), and incorrect responses (less than 5% of the data) were excluded from the reaction time analysis. Due to violations in sphericity, Greenhouse-Geisser estimates of sphericity are reported for degrees of freedom.

Lexical decision times. Mean lexical decision times were calculated for each prime condition. There were no significant differences in the amount of facilitatory priming for subset items based on whether 1 or 2 letters were omitted; therefore, the data reported are collapsed over these variables. Correct "word" lexical decision times in the identity, subset and non-words prime conditions were analyzed using a mixed between-within subject analysis of variance with font change as the between subject factor. Prime type was significant, $F(1.9,778.9) = 494.09$, $p < .001$, $\eta_p^2 = .54$. The between subject factor and interaction failed to reach significance ($p > .05$). An a priori pair-wise *t*-test further explored prime type differences between identity ($M = 594$; $SD = 55.89$), subset ($M = 610$; $SD = 52.66$), and non-word ($M = 633$; $SD = 52.53$). The *t*-tests verified that identity primes produced significantly shorter target word lexical decisions than subset primes ($t(415) = 11.42$, $p < .001$, $d = .71$). Identity and subset primes produced significantly shorter target word lexical decisions than non-word primes, $t(415) = 38.06$, $p < .001$, $d = 3.74$, $t(415) = 22.61$, $p < .001$, $d = 2.22$, respectively (see Figure 3.1).

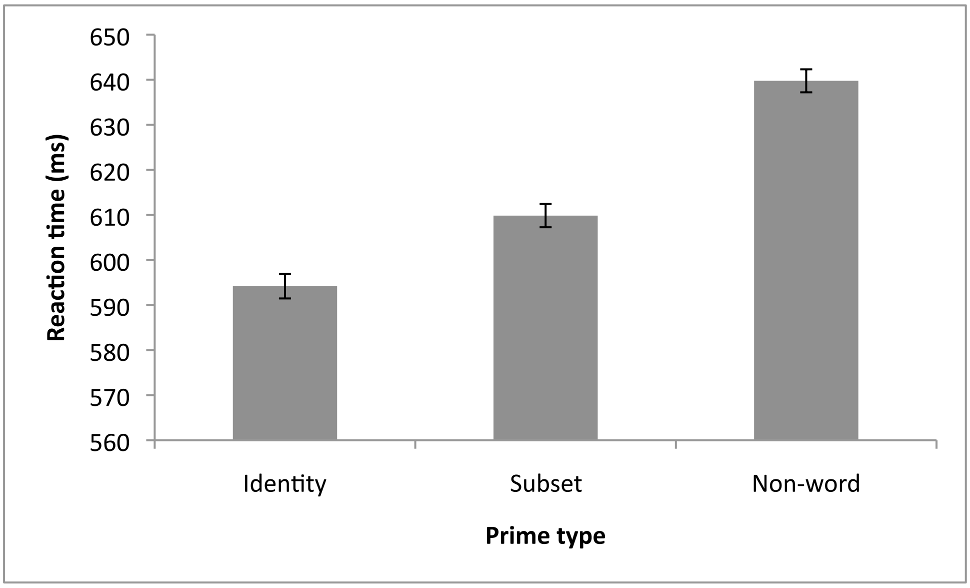

Figure 3.1. Reaction time for correct responses, error bars depict standard error of the mean

Accuracy. Accuracy data mirrored reaction time results with both font type and 1 or 2 letters omitted; therefore, the data reported are collapsed over these variables. The resulting identity, subset, and non-words were analyzed using a mixed between-within subject analysis of variance with font change as the between subjects factor. Prime type was significant, $F(1.5, 633.3) = 50.16$, $p < .001$, $\eta^2 = .11$. There was no main effect or interaction for the font change manipulation (*ps* > .05). An a priori pair-wise *t*-test was used to further explore prime type differences between identity ($M = .92$; $SD = .08$) and subset ($M = .90$; $SD = .07$) prime conditions. Target probes preceded by the identity condition were responded to more accurately than target probes preceded by the subset condition $t(415) = 5.37$, $p < .001$, $d = .52$. Identity and subset primes produced significantly improved accuracy relative to a non-word prime, $t(415) = 14.87$, $p < .001$, $d = 1.46$, $t(415) = 3.42$, $p = .001$, $d = .34$, respectively. The error analysis thus consistently mirrored the RT analysis (see Figure 3.2).

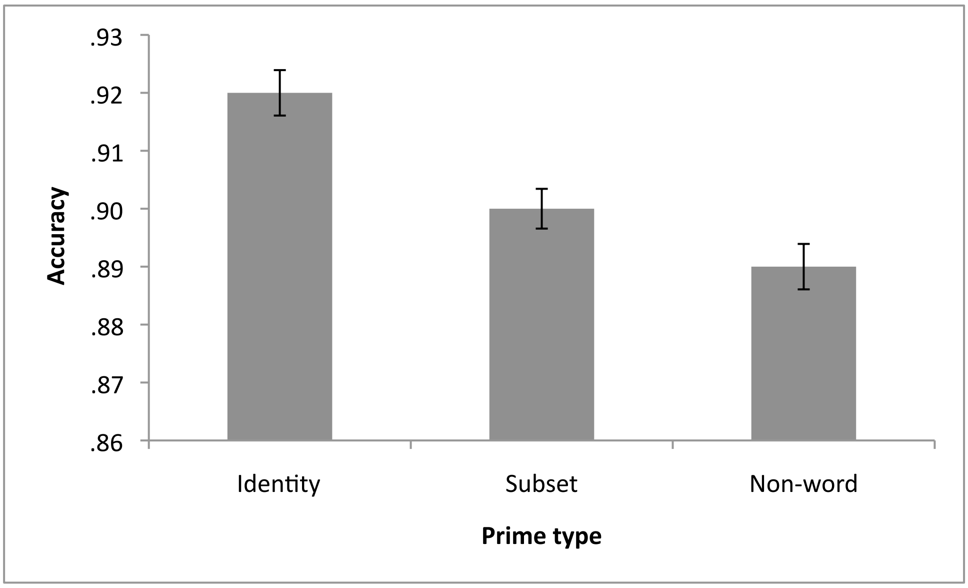

Figure 3.2 Proportion correct for prime conditions, error bars depict standard error of the mean.

Correlation. To explore the influence of sex, age, and number of text messages sent a day we correlated each of these with a measure of priming performance of subset primes. For priming performance we calculated the difference in RT between target words preceded by subset and identity words to establish magnitude of priming for each participant (see Head, Helton et al., 2011 for similar procedure). Magnitude of priming was then separately correlated with sex, age, and number of text messages sent a day. Sex and age failed to correlate with priming magnitude (r = .06, r = .02, ps > .05, respectively); however, number of text messages sent a day did significantly correlate with priming magnitude (r = -.11, p =.03).

3.10 Discussion

This study collected text-speak words and phrase representations from native New Zealanders to create a normed stimuli list. A sample of subset words were selected from the normed stimuli list and used within a masked priming experiment. The masked priming experiment consisted of correctly spelled primes (identity), primes with either 1 or 2 letters omitted (subset) and non-word primes that preceded target probes. As expected, the identity prime condition produced greater accuracy and faster responses to target probes compared to subset and non-words primes. Moreover, subset primes produced greater accuracy and faster reaction times to target probes compared to non-word primes. In regards to sex and age, the text-speak questionnaire failed to show any significant correlation with these items and magnitude of priming. However, those who reported sending more text messages each day displayed greater subset priming effects.

The results mirrored the results found in Head, Helton et al. (2011). Identity primes produced faster and more accurate responses to target probes compared to subset and non-word primes. Additionally, subset primes produced faster and more accurate responses to target probes compared to non-word primes but not identity primes. Importantly, regardless of whether the prime and probe were presented in different fonts (feature overlap degrading), priming effects for each prime type was not altered. In other words, if participants were using feature matching as a subconscious strategy for their target probe responses, then priming effects should have been significantly diminished compared to the group that had the prime and probe in the same font. Based on the greater priming effects of subset primes compared to non-word primes, our results further corroborate that text-speak word representations do possess a level of lexical representation and are not dependent on feature matching at a subconscious level.

The subset prime results suggest that participants interpreted a subset as word-like which was evident from the greater priming effects of subset primes relative to non-word primes. However, subset words failed to produce the same level of priming as identical primes. This may in part be due to subset words not being automatically activated like their correctly spelled analogue. As found in Head, Russell et al. (2011), participants responded more slowly and with a greater number of errors as a result of processing subset items. Interestingly, subset words' lack of automatic activation relative to correctly spelled words seems to be extended to the subconscious level of processing. Thus, even without conscious awareness, subset words are more difficult to process and may demand additional mental resources to process. However, given the experimental design it is difficult to make that conclusion. Future studies should include methodologies to further elucidate the mental resource demands of processing subset words.

Conscious processing of stories presented in text-speak versus correctly spelled stories has been shown to exact a cognitive cost to the reader (Head, Helton, et al., in press). The reader is not only presented with subset representations but also a host of other text-speak representations (e.g., **Cn u cm ova 2nite pls?** Can you come over tonight please?). This paradigm makes it difficult to infer whether subsets alone demand additional mental resources to process. To address this predicament, the current study presented subset words subconsciously and isolated from context effects. Similarly as found in Head, Russell, et al. (submitted) reaction time and error rate both increased as result of processing subset items compared to processing correctly spelled words. The results provide evidence that subset items although having some of the lexical properties of words cannot be considered as representationally equivalent to words.

Although there was no relationship between age and sex with priming magnitude, there was a significant correlation between the number of self-reported text messages sent a day and priming magnitude for subset primes. This significant correlation supports the finding that more practice on a task can yield greater task performance (Fitts & Posner, 1967; Gibson, 1969). People who reported higher numbers of text messages sent a day are likely to have had more practice reading and producing text-speak than those who reported lower frequency of daily text messaging. This result suggests that participants who text message often are likely to encounter text-speak more frequently and thus benefit more from a subset prime in a masked priming task, relative to people who text less.

The correlation coupled with the masked priming results described above fits well within the framework of the IA model. Returning to the foreign language analogy previously discussed, when a person first encounters a foreign word, they will likely have less excitatory influence from the top-down level word processing. However, as experience with the foreign word increases so does the potential for excitatory activation from the top-down level processes. Therefore, in relation to the masked priming results, participants with less experience with text-speak likely did not receive adequate excitatory activation needed to facilitate priming for the target probe when presented with a subset prime. Conversely, people who are more accustomed to text-speak had greater excitatory influence as evident from greater facilitatory priming performance.

A limitation should be noted in regards to the correlation. Because we wanted to systematically investigate the impact of subset items on priming effects we employed a high number of normed subset word representations ($N = 280$). Although this approach provides more control of the word stimuli, it may not encompass many of the text-speak items that participants use frequently. In other words, we may have forced upon the participant subset words that they do not commonly have in their repertoire. This may explain the small correlation between priming magnitude and number of text messages sent a day. Additionally, the focus of this study was subset words, future studies should examine other forms of text-speak (e.g., shortcuts, phonetic respellings and numerals) in a masked priming experiment to determine whether those word representations possess semantic meaning.

Collectively, the results support the idea that a specific form of text-speak (i.e., subset) does possess a level of semantic meaning and does not require sentence context for activation. The current study was able to show that feature overlap was not driving the priming effects found previously in Head et al. (2011). Lastly, the current investigation showed that the IA model is pertinent when interpreting experience and masked priming subset primes. As the use of text based communication increases within civilian and military occupations, so does the likelihood of text-speak appearing. Thus, if text-speak is going to be used in either arena, then there should be standardized ways of shortening words or phrases to reduce the chances of misinterpretation of a message.

Summary and Conclusion. In Chapter 3, the masked priming results revealed that text-speak primes, relative to its correctly spelled analogue, resulted in more errors and slower responses to correctly spelled target probes. Although statistically significant, the differences between text-speak and correctly spelled stimuli for accuracy and response time were relatively small (e.g., text-speak: accuracy = .90, RT = 610 ms; correctly spelled: accuracy = .92, RT = 594 ms). Additionally, the masked priming paradigm provided evidence that text-speak items have lexical representation and are more difficult to process. However, it failed to adequately address the cognitive burden text-speak may place on the reader. Thus, a task was needed whereby performance impairments are associated with increases in cognitive demand. In Chapter 4, two proposed measures of sustained attention were chosen to assess cognitive cost of text-speak for three reasons. Firstly, sustained attention is sensitive to task demand, with increases in cognitive load being associated with increased performance impairments (Davies & Parasuraman, 1982). Secondly, the use of sustained attention also provided a unique opportunity to test two theoretical interpretations of a proposed measure of sustained attention (i.e., Sustained Attention to Response Task or SART; Robertson, Manly, Andrade, Baddeley, & Yiend, 1997). Third, although the use of word stimuli in a SART is not a novel concept (e.g., Smallwood et al., 2006), the inclusion of text-speak items as stimuli in a traditional vigilance task or SART has not been previously explored. Therefore, in chapter 4 we further explore the cognitive cost of processing text-speak using the SART and a traditional vigilance task. Additionally, we further explore the effects of experience with text-speak on performance on the SART and traditional vigilance tasks.

CHAPTER 4

Text-speak Processing and the Sustained Attention to Response Task[3]

4.1 Abstract

We examined performance in a Sustained Attention to Response Task (SART) (Experiment 1) and a more traditionally formatted vigilance task (Experiment 2) using novel word stimuli (text-speak) and normally spelt words. This enabled us to investigate the cognitive demands of text-speak processing and whether the SART is a better measure of sustained attention or response strategy. In Experiment 1, 72 participants completed a subset (text-speak) and a word SART, as well as a self-reported text experience questionnaire. Those who reported more proficiency and experience with text-speak made more errors on the subset SART, but this appeared to be due to their increase in response speed. There was no tendency for those more proficient and experienced with text-speak to make more errors when the stimuli were words. In Experiment 2, 14 participants completed high No-Go, low Go (more traditional response format for vigilance tasks) task using word and text-speak stimuli to further investigate the cognitive demands of text-speak processing. Response latency increased over periods of watch only for the text-speak task, not for the word task. Taken together the results of experiments 1 and 2 indicate that vigilance tasks provide a novel way for investigating the cognitive demands of text-speak processing. Results from Experiment 1 were interpreted to support the perspective that the SART is highly sensitive to response strategy not sustained attention as commonly claimed.

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4.2 Introduction

Vigilance is the ability to sustain attention and stay alert over prolonged periods of time (Davies & Parasuraman, 1982; Matthews et al., 2010; Warm, 1993). The traditional vigilance task with low Go rates involves an observer responding to rare signals within a Go/No-Go detection task. Observers are required to make overt responses to relatively rare critical signals in the presence of more frequent neutral stimuli. Typically there is a decline in performance as a function of time on task, the vigilance decrement, which is indicated by either a decrease in detection rates over time or an increase in response latency over time. The decrement can be seen within the first 15 min of watch (Teichner, 1974) and even as early as 5 min (Helton, Dember, Warm, & Matthews, 2000; Temple et al., 2000).

Robertson and colleagues developed the Sustained Attention to Response Task (SART; Robertson, Manly, Andrade, Baddeley, & Yiend, 1997) as an alternative methodology to investigate lapses of sustained attention. The SART differs from the traditional vigilance task in that observers are required to respond overtly to the frequent neutral stimuli, which occur 80-90% of the time, and to withhold responses to rare critical signals that occur 10-20% of the time. In the SART the primary performance measure of interest are the errors of commission (e.g., inappropriate response to critical signals). The SART has been widely used to measure lapses of sustained attention (Chan, 2001, 2002; Dockree et al., 2004, 2006; Johnson et al., 2007; Manly, Robertson, Galloway, & Hawkins, 1999; Smallwood et al., 2003; Smallwood et al., 2004). Alternatively, it has been argued that the SART is a measure of participants' response strategy and impulsivity, not sustained attention per se (Helton, 2009; Helton, Kern, & Walker, 2009; Helton et al., 2010; Peebles & Bothell, 2004).

In addition to the debate over what the SART measures, there is an on-going dispute regarding what mechanisms are responsible for lapses of sustained attention. The originators of the SART have proposed that errors occurring during vigilance tasks are due to participants' mindlessness (Roberton et al., 1997). Due to the monotonous nature of vigilance tasks, errors reflect observers' mental disengagement or 'absentmindedness' from the task (Smallwood & Schooler, 2006). Conversely, this theoretical explanation has been challenged from a resource theory perspective (Grier et al., 2003; Helton, 2009; Helton et al., 2005; Helton, Kern, & Walker, 2009; Helton & Warm, 2008). Resource theorists argue that lapses in attention during vigilance tasks are due to resource depletion caused by the high mental demands of sustained attention tasks (Davies & Parasuraman, 1982; Helton et al. 2000, 2005, 2009; Matthews et al., 2010; Warm et al. 2008).

The SART is demanding in that it requires frequent and repetitive responses throughout the task. Helton and colleagues (2005) propose that the majority of errors of commission on the SART are better explained by failures of response inhibition than failures of perceptual awareness (sustained attention). During the SART a self-organizing feed-forward ballistic motor program develops. Moreover, they argue that the pre-potent ballistic motor program instantiated by the multiplicity of Go responses is not well controlled when a target (No-Go) signal occurs. This explains why participants are often fully aware of making errors of commission during the SART, but attribute these errors to their offending hands, a phenomenon referred to as alienation of agency (see Cheyne, Carriere, & Smilek, 2009).

In the present study, we employed a novel set of stimuli in the SART, namely correctly spelt complete English words and subset word stimuli (text-speak) formed by deleting one letter from English words. Smallwood and colleagues (2006) previously utilized a semantic SART, in which participants responded to the frequent appearance of 5-letter words and withheld responses to a rarely occurring non-word target (XXXXX). Despite the use of words, they obtained errors, and this opened up the possibility of using word stimuli in the SART. Word recognition is a well-practiced and nearly automatic activity (Stroop, 1935). For literate people words capture attention (Johnston, Hawley, Plewe, Elliot, & Dewitt, 1990). Therefore, word stimuli have rarely been employed in traditionally formatted vigilance tasks, because words were deemed unlikely to elicit a decline in vigilance with time-on-task (i.e., no vigilance decrement; see Brown, Gore, & Carr, 2002). A semantic SART should be more attention engaging and capturing for more literate people than for less literate people. Words for those who are literate elicit richer meaning and therefore, should provide exogenous support for their performance. Controlling for literacy, a SART requiring the recognition of a rare word target imbedded in a stream of more common word stimuli offers the possibility of assessing the two interpretations of SART performance: mindlessness (perceptual unawareness) vs. response strategy. If the mindlessness perspective is correct and commission errors on a SART are primarily the result of perceptual unawareness (i.e., failures of sustained attention), then more literate individuals should perform better than less literate individuals. If the SART primarily measures response speed and strategy, highly literate individuals would be more likely to respond quickly to word stimuli and, therefore, would actually be more likely to make commission errors than less literate individuals. From this perspective, commission errors result from speeded responses and literate individuals would more quickly recognize the stimuli. A study using correct word stimuli alone poses two challenges: finding functionally illiterate participants who can follow experimental instructions, and the fact that individuals who drastically differ in literacy in developed societies are likely to differ in other characteristics, which may influence SART performance. However, there is a novel language form which shows individual differences of use in developed countries, namely text-speak.

How individuals communicate has evolved from handwritten letters to more complex digital representations (e.g., online instant messaging, emailing, text messaging; Crystal, 2008). These new means of communication have had a profound effect on how words and sentences are represented (Crystal, 2008; Head et al., 2011). Indeed, new innovations in language production and representation have yielded techniques that allow individuals to send messages faster and with more content. This new innovative approach to language is called text-speak. For example, individuals use acrostics (e.g., **gtg**-got to go), shortcuts (e.g., **2nit**-tonight) and subsets (**txt**- text) to produce word or phrases relatively quickly while maintaining semantic meaning (Ganushchak, Krott, & Meyer, 2010; Head et al., 2013; Thurlow, 2003). The current study focused on subset words. Recent studies have demonstrated that subset words do elicit semantic meaning (Head et al., 2011; Perea & Gomez, 2010). Individuals differ in their proficiency and experience in text-messaging (Head et al., 2011). Perea, Acha, and Carreiras (2009) found that experienced text messengers can comprehend the meaning of complex test speak phrases with high competence (e.g., Can you come out tonight, **cn u cm out 2nite?**).

In Experiment 1 of the present research participants performed two SARTs: a word SART and a subset SART. Participants in the word SART were instructed to withhold a response to the word “text” and to respond to 8 other 4-letter words. In the subset SART, participants were instructed to withhold a response to the subset “txt” and to respond to 8 other 3-letter subset words. If Robertson and colleagues are correct, individuals who report proficiency and more experience in text-messaging should have better performance on the subset SART than those with less experience. The subsets should be read efficiently and elicit meaning nearly automatically, like correctly spelt words, for experienced text-messengers. Thus, for these individuals, subsets should provide exogenous support for task performance. If, however, commission errors in the SART are primarily due to quick responses overall, then the opposite should occur. Highly experienced text-messengers will recognize the subset word stimuli more efficiently and will therefore speed up their overall response rate. As they are responding more quickly, they will in turn be more likely to make errors of commission than those who text-message less frequently (who will respond more slowly). We employed the word SART to reveal whether high and low text-messengers are simply different in SART performance generally.

4.3 Experiment 1

4.4 Method

Participants. Seventy two undergraduate students (13 men; 59 women) from introductory psychology classes at University of Canterbury served as participants for course credit. All participants had normal or corrected-to-normal vision. Participants ranged in age between 19 and 55 years (*M* = 23.44 years, *SD* = 6.30).

Word stimuli. Sixteen 4-letter words having a frequency of at least 25 occurrences per million in the SUBTLEXus database (Brysbaert & New, 2009) were selected from the subset and text speak norms (Head et al., 2013). A 3-letter subset was created for each word. These were divided into two sets of 8 words and correspondingly two sets each of 8 subsets for counterbalancing purposes. Each participant completed a block of word SART trials and a block of subset SART trials. In word SART blocks participants responded to each of the repeatedly presented 8 words (neutral stimuli) and withheld responses to the occasionally presented target “text”. In subset SART blocks participants responded to each of the repeatedly presented 8 subsets (neutral stimuli) but made no response to the target “txt”. Targets and neutral stimuli were presented in various alternating cases (e.g., TeXt, tXt, TeSt, TST) to encourage participants to read the word rather than rely on memory for one perceptual form of the target.

Text questionnaire. The text speak proficiency questionnaire (Chapter 2) is a 9-item self-reported questionnaire that consists of 3 factors: willingness to use text-speak, overall text messaging experience, and preference to use text messaging. For the present study we were interested in the text-messaging experience factor which consists of two items: (1) on average, how many text messages do you send a day, and (2) I text message very often.

Procedure. The participants were tested in individual cubical stations. They were seated 50 cm in front of video display terminals (377 mm x 303 mm, 75 Hz refresh rate) that were mounted at eye level. The participant's head movement was not restrained. Participants surrendered their wristwatches and cell phones. Stimuli presentation and recordings of reaction times and accuracy were performed by personal computers running E-prime Professional 2.0 (Schneider, Eschman, & Zuccolotto, 2002). Participants were randomly assigned to order of presentation groups. Group 1 completed a block of word SART trials followed by a block of subset SART trials. Order was reversed for group 2. Each block was 9 min in duration. Two separate practice trials, one for word and one for subset SARTs, were used before each block to allow participants to familiarize themselves with targets and neutral stimuli. Participants were instructed to withhold responses to target (e.g., text or txt) and to respond to neutral stimuli. Targets and neutral stimuli were presented in light grey Arial size 18 font. The case of targets and neutral stimuli were alternated (e.g., TeXt, tEsT) to encourage participants to read the word and minimize perceptual strategies. Targets and neutral stimuli were each presented for 250 ms at a rate of 48 events/min centred against a visual grey grid consisting of unfilled circles on a white background (see Figure 4.1).

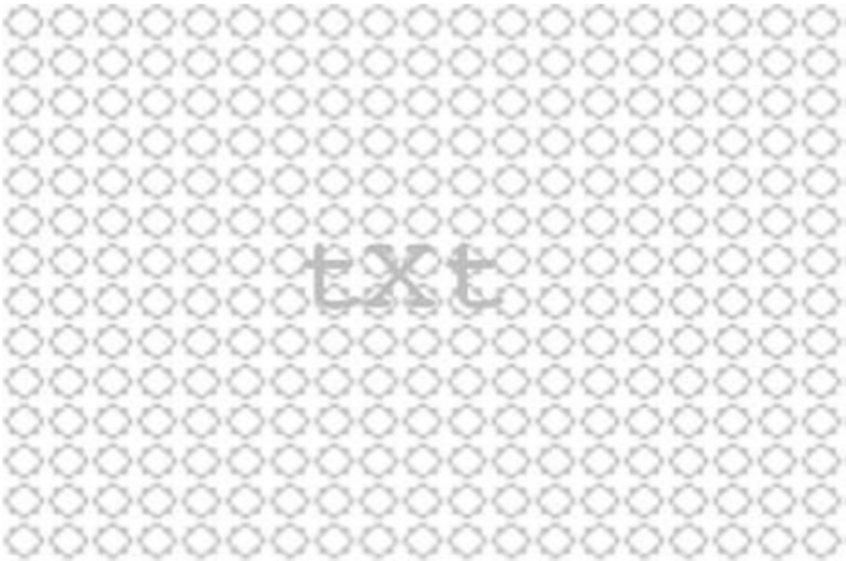

Figure 4.1. Subset target on circular grey mask

The circular elements of the grid were 5mm in diameter and were out-lined by 1 mm thick grey lines (see Helton et al., 2010 for similar procedure). Each 9 min task was divided into four continuous 2.25 min periods. The order of presentation of targets and neutral item stimuli was varied randomly within each period of watch for each participant. The only restrictions were that the targets occurred with the probability $p = .11$ and the neutral items occurred with a probability of $p = .89$. Participants' responses to stimuli were made via a serial response mouse. Responses occurring within 950 ms after the onset of the critical targets were recorded as errors of commission and neutral stimuli not responded to were recorded as errors of omission. Upon finishing the two SART blocks, participants completed the text-messaging questionnaire.

4.5 Results

Performance. We calculated the percentage of errors of commission and omission for each individual for each 2.25 min period of watch. The mean commission errors, omission errors and correct response times for the tasks are presented in Table 4.1.

Table 4.1

Percent error of commission, omission and reaction time (ms).

Task	Commission	Omission	Reaction time	
SART-Text	54.1 (3.0)	1.3 (0.3)	361 (7.5)	
SART-Txt	55 (2.9)	2.0 (0.6)	353 (7.7)	
				N = 72
TFT-Text	0.4 (0.2)	1.3 (1.2)	498 (10.1)	
TFT-Txt	0.3 (0.2)	0.9 (0.7)	503 (13.5)	
				N = 14

Note: Sustained attention to Response Task (SART);
Traditional formatted Task (TFT).
Values enclosed by parentheses represent standard error.

Commission and omission data were treated by separate 2 (word vs. subset) x 4 (periods of watch) repeated measures ANOVA. For commission errors the only significant effect was period of watch, $F(3,213) = 6.71$, $p < .001$, $\eta_p^2 = .09$. Mean percent commission errors increased from 51% to 58% across watch periods. The analysis of omission errors also revealed a significant main effect for period of watch, $F(3,213) = 3.25$, $p = .023$, $\eta_p^2 = .04$, indicating that omission errors also increased with time on watch. There was a trend for more errors of omission in the subset ($M = 2.0$ $SE = 0.5$) than the word task ($M = 1.4$, $SE = 0.3$), $F(1,213) = 3.23$, $p = .076$, $\eta_p^2 = .04$. There was, moreover, a significant interaction between period of watch and SART task for omission errors, $F(3,213) = 2.98$, $p = .032$, $\eta_p^2 = .04$. The mean percentages of omission errors for both text tasks for each period of watch are displayed in Figure 4.2.

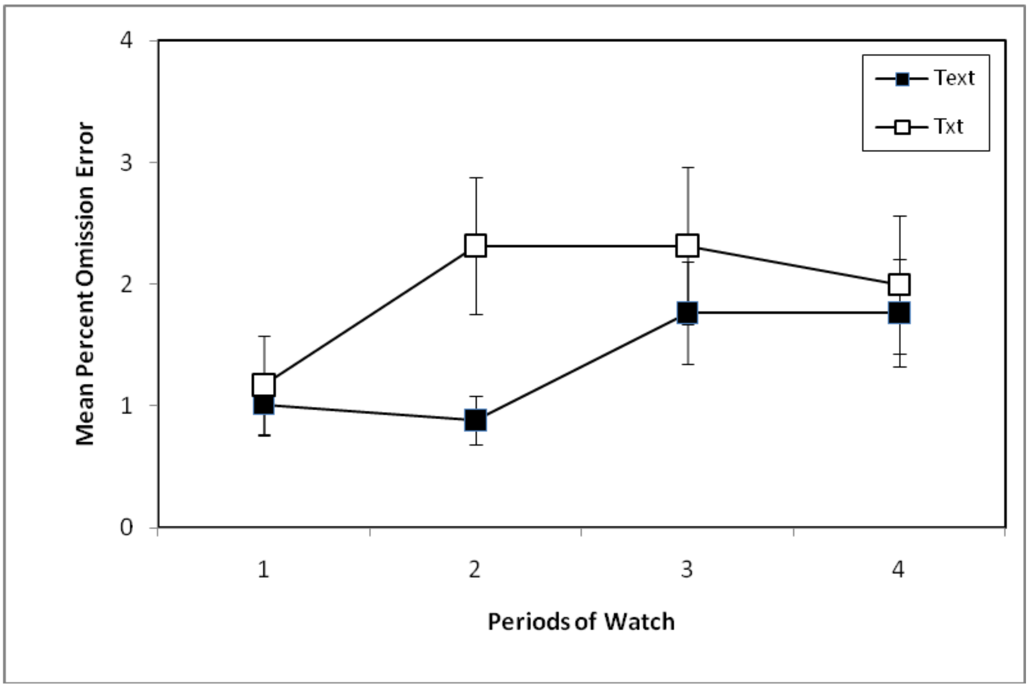

Figure 4.2. Subset-txt and word-text SART error of omission by period of watch, error bars depict standard error of the mean

The significant interaction was followed up with independent repeated measure ANOVAs for the word SART and subset SART. These were significant for both the subset-SART, $F(3,213)= 2.72$, $p = .046$, $\eta_p^2 = .04$, and the word SART, $F(3,213) = 4.00$, $p < .01$, $\eta_p^2 = .05$. For each task the mean response times (RT) of correct responses were calculated for each participant. The mean response times were subjected to a 2 (word vs. subset) x 4 (periods of watch) repeated measures ANOVA. There were no statistically significant effects, $p > .05$.

Relationships between Performance Metrics and Self-reported Text Experience. Table 4.2 reports the relevant correlations between performance metrics and self-reported text experience. Both commission and omission error rates increase significantly with texting experience in the subset SART. Corresponding correlations for the word SART are not significant.

Table 4.2.

Correlations (n = 72, word SART above the main diagonal; subset SART below)

	Texting	Commissions	Omissions	Reaction Time
Texting		.15	.15	-.04
Commissions	.29*		.43*	-.79*
Omissions	.23*	.31*		-.49*
Reaction Time	-.33*	-.79*	-.55*	

*Note: p < .05 **

Importantly, response times decrease with texting experience but only in the subset SART. Further, in both word and subset SARTs commission and omission errors are both significantly negatively correlated with response time – the faster the response the greater the error rate.

Further, to establish a mediating role for response speed in the relationship between texting experience and error rates in subset SART, linear regression analyses were applied to the subset SART data as outlined by Baron and Kenny (1986). First, a model was tested to see if self-report text-messaging predicted response time in the subset SART. This model was significant, $F(1,70) = 8.55$, $p < .01$, $R^2 = .11$, $\beta = -.33$, $t = 2.92$. Models were then tested to see if self-reported text-messaging predicted errors of omission and commission. Both of these models were also significant, $F(1,70) = 3.95$, $p = .05$, $R^2 = .05$, $\beta = .23$, $t = 1.99$ and $F(1,70) = 6.23$, $p = .02$, $R^2 = .08$, $\beta = .29$, $t = 2.50$, respectively. In the mediation test, step models were tested to see if self-reported text-messaging was no longer a significant predictor when response time was introduced into the predictive models for errors. In both cases this was true, errors of commission, total model $F(2,69) = 58.92$, $p < .01$, $R^2 = .63$ (text-messaging $\beta = .03$, $t = .35$, $p > .05$) and errors of omission, total model $F(2,69) = 14.78$, $p < .01$, $R^2 = .30$ (text-messaging $\beta = .06$, $t = .54$, $p > .05$). Taken together these analyses support the view that the major determinant of commission and omission errors in the subset SART is response speed, rather than experience texting.

4.7 Discussion

For Experiment 1 we examined performance using two SARTs (word and subset) to explore competing theoretical explanations for lapses of sustained attention. The results revealed that SART tasks involving word stimuli induce errors relatively quickly. From Robertson's and colleagues' account of the SART, errors and response times should have all decreased with texting experience in the subset SART. From this perspective subset SART error rates and response times will all correlate negatively with texting experience as subset stimuli will exogenously support attention for those highly proficient in text-speak. Conversely, from Helton's and colleagues' account of the SART, the correlation between response time and experience should have been negative, while a positive correlation should have occurred between errors and text-speak experience in the subset SART. The correlation matrix in Table 4.2 revealed that self-reports of frequent text messaging correlated positively with errors and correlated negatively with response times for text-speak subset representations. These findings are exactly in line with Helton's and colleagues' perspective. Indeed, to further examine the influence of proficiency and experience with text-speak and response time as predictors of errors (i.e., commission and omission), we utilized a mediation step model to examine their relationships in the subset SART. It was revealed that when response time is introduced into the model, individuals' proficiency and experience do not predict errors of commission or omission, rather response time is a mediator. Once response time is entered into the regression model, text-speak proficiency no longer predicts errors. Indeed, in line with Helton's (2009) account of the SART, there are negative relationships between errors and response times in both SARTs, indicative of speed-accuracy trade-offs. The SART does appear to be highly sensitive to response strategy.

4.8 Experiment 2

In Experiment 1 word and subset detection tasks offered the opportunity to better elucidate the nature of text-message processing, independently of the measurement issue of the SART. Text-speak is considered more cognitively demanding than reading correctly written words in sentences (Salvucci, 2001; Reilly & Radach 2006). Indeed, in an applied setting, Knott et al. (2006) showed that text-speak messages are produced faster than completely spelled messages but they also induce higher error rates for interpretation. Arguably, this increased cognitive cost of text-speak may be amplified by time-on-task and requirements for sustained attention. We were, therefore, interested in whether the subset and word versions of the tasks differed in overall performance with time-on-task. We modelled the current tasks therefore on a task used previously to elicit a vigilance decrement with letter stimuli in short durations, less than 6 min (see Temple et al., 2000; Helton et al., 2000; Helton & Russell, 2011a). Therefore, in Experiment 2, we reversed the response paradigm of the SART to a more traditional vigilance format of low-Go, high No-Go, to better resolve the interpretation of both our SART findings and to provide a more complete picture of the word-text and subset-txt performance differences.

4.9 Method

Participants. Fourteen undergraduate students (6 men; 8 women) from psychology classes at University of Canterbury served as participants for course credit. All of the participants had normal or corrected-to-normal vision. Participants ranged in age between 20 and 38 (*M* = 24 years, *SD* = 5.17).

Procedure. The procedure was identical to Experiment 1, except participants in this task performed the two tasks with a more traditional response format for a vigilance task (i.e., low-Go, high No-Go). Participants in this experiment responded to the “text” or “txt” words, but withheld response to all other stimuli. Otherwise, the tasks in Experiment 1 and

Experiment 2 were perceptually identical. Because of low sample size of this experiment we did not use the text-messaging questionnaire.

4.10 Results

Errors of Commission and Omission. We calculated the percentage of errors of commission and omission for each participants for each period of watch. The mean performance metrics for these tasks are presented in Table 4.1. These percentages for word and subset tasks were subjected to 2 (word vs. subset) x 4 (periods of watch) repeated measures ANOVA. For commission errors there were no significant effects, $p > .05$. Indeed, the overall mean percentage of errors of commission across both tasks was nearly zero, M = 0.3% (floor effect). For omissions the only significant effect was the main effect for period of watch, $F(3,39) = 3.43$, $p = .026$, $\eta_p^2 = .21$. Omission errors increased from 0.4% to 2.5% over the four watch periods.

Response Times to Correct Responses. For each task the mean response times of correct responses were calculated for each participant. The mean response times were subjected to a 2 (word vs. subset) x 4 (periods of watch) repeated measures ANOVA. There was a significant main effect for period of watch, $F(3,39) = 7.54$, $p < .001$, $\eta_p^2 = .37$, and a significant interaction between period of watch and text condition, $F(3,39) = 3.10$, $p = .04$, $\eta_p^2 = .19$. There was no significant main effect for task, $p > .05$. The mean reaction times for both text tasks for each period of watch are displayed in Figure 4.3 below. The significant interaction was explored with independent repeated measures ANOVAs for the word and subset vigils. The analysis was significant for the subset trials, $F(3,39) = 7.95$, $p < .01$, $\eta_p^2 = .38$, but not for the word trials, $F(3,39) = 1.63$, $p > .05$.

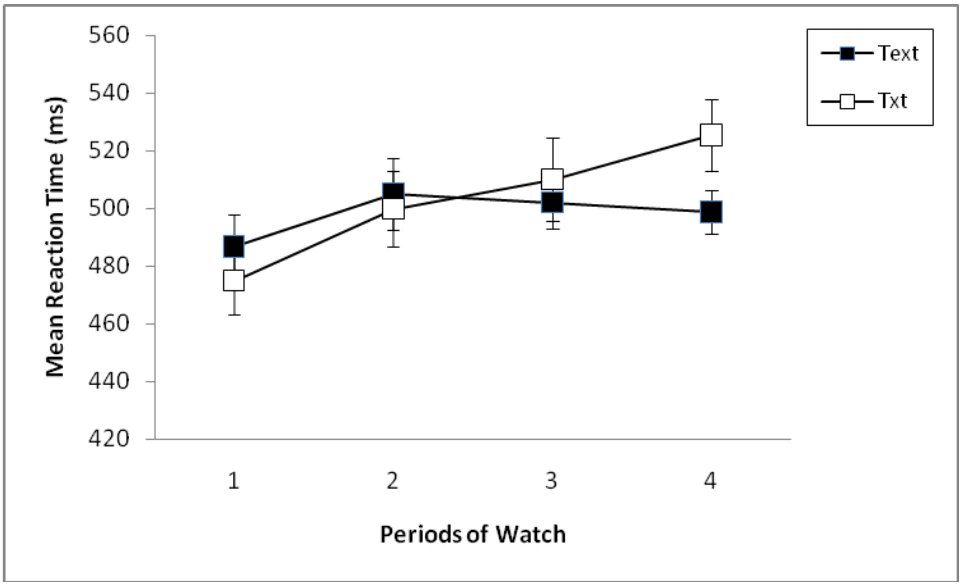

Figure 4.3. *Reaction time for correct responses for subset-txt and word-text, error bars depict standard error of the mean.*

4.11 Discussion

Results from Experiment 2 suggest that vigilance performance is contingent upon cognitive load of the detection task. There was an overall increase in omission errors (or misses in traditional tasks) for both tasks over periods of watch. The more sensitive metric in this case was response latency. In this case, response time increase with periods of watch for the subset detection task, but not for the word detection task. These results implicate that subset (text-speak) processing may indeed be more cognitive demanding and susceptible to fatigue than word processing.

4.12 General Discussion

In the present study, self-reports of frequent text messaging correlated positively with errors of commission and correlated negatively with response times in a subset SART. These relationships were non-significant for a word SART. If the SART measures mindlessness and perceptual disengagement from the task, this is a difficult finding to interpret. Meaningful words should exogenously capture attention (see Johnston et al., 1990). Those proficient in text-speak should be more likely to extract semantic meaning from the subset word form. For these proficient users, the subset words should therefore serve as prompts or external supports for attention. As an analogy, we would expect a proficient English language user to be more mindful during a lecture in English, than one given in Chinese, even if they knew some Chinese. If on the other hand, the SART is sensitive to response strategy (speed-accuracy trade-offs), then we would expect those proficient in text-speak to be quicker and, thus, make more errors. If they respond to the subset stimuli more rapidly (as they read them more quickly), they are then more likely to make errors of commission in the SART. This theory was supported by the findings. The SART seems highly sensitive to speed-accuracy tradeoffs. Indeed in comparison to the a more traditionally formatted low-Go task (Experiment 2), participants on both SARTs responded more quickly and made more errors of commission. If errors of commission are a measure of perceptual engagement, it is interesting that a simple change in response format for perceptually identical tasks can switch people from near 100% engagement to less than 50% engagement. We suspect this is unlikely. Instead errors of commission in the SART are more often errors of motor control, not errors of perception.

During the SART participants need to self-regulate and inhibit their pre-potent responses. Although the main focus of SART studies is on errors of commission, errors of omission do occur within SARTs. Errors of omission are usually the primary performance metric of interest in traditional low-Go vigilance studies (Davies & Parasuraman, 1982; Helton & Warm, 2008; Mackworth 1948, 1950/1961; Matthews, Davies, Westerman, & Stammers, 2000; See, Howe, Warm, & Dember, 1995; Warm, 1984). Advocates of the SART have argued that errors of omission are due to off task episodes (task unrelated thoughts) or on-task episodes (task related thoughts). Conversely, Helton and colleagues (2005, 2009), argue that the SART is a measure of speed-accuracy trade-off and response strategy. Thus, the errors of omission could be tactical forced rest-stops (Helton et al., 2010; Helton & Russell, 2011b). Indeed, this strategy could disrupt the pre-potent motor program that is induced by the SART and thus cause inappropriate withholds to non-targets. Indeed text messaging experience correlated with errors of omission during the subset SART, but not for the word SART. This is odd if in the SART errors of omission are always measures of complete perceptual disengagements during the task. If anything, we would expect the subset words to automatically capture attention in proficient text-messaging users. Perhaps because the proficient text-speak users are responding more quickly in the subset SART and make more errors of commission, one attempt to regain motor control during the task is to for them to take occasional rest-stops (Helton, Head, & Russell, 2011). This would suggest that the errors of omission could be due to motor rest-stops or 'taking a breather' (Helton, Head, & Russell, 2011) and not solely due to disengagements of perceptual awareness.

Errors of omission increased over-time in both the SART (Experiment 1) and traditionally formatted task (Experiment 2) for both subset and word stimuli. However, it is still unclear how metrics in the SART and traditionally formatted vigilance task map. Indeed, errors of commission also increased in the SART with time-on-task, but did not in the traditionally formatted task. The SART muddles response strategy (response inhibition) with sustained attention to an extent that clarifying what processes are actually causing the error is difficult. In the SART, the increase in errors of omission occurred earlier in the subset version than the word version; there was no significant difference in the traditionally formatted task. Whether errors of omission in the SART are perceptual disengagements or forced rest-stops (and indeed, they may both be occurring), either explanation would imply the subset SART was more demanding than the word SART. While we did not detect any differences in the traditionally formatted task for errors, we did detect a difference between the subset and word tasks for response times with time-on-task. There was a significant increase in response times in the subset task with time-on-task, this did not occur for the word task. Previous research indicates a cognitive cost with subset processing, as even highly proficient text-messengers are unlikely to be as proficient with text-speak as they are with correctly written language (Knott et al., 2006). The present findings are intriguing and sustained attention tasks may be a novel way to investigate the cognitive costs of text-speak processing.

While the SART and traditionally formatted tasks, if extended in duration, can both presumably measure changes in sustained attention, the SART performance metrics are very sensitive to response strategy. In the SART, it is immensely difficult to resolve whether an error is the result of perceptual unawareness to the task stimuli (vigilance) or simply the failure to inhibit the pre-potent motor response (going fast). If the primary interest is sustained attention, traditionally formatted low-Go tasks are a better option; they do not confound strategy with vigilance. The SART is still, however, a useful and interesting task. As demonstrated in the present study, a high-Go, low No-go task in which the stimuli are subset words results in *less accurate* performance for proficient text-messengers. Aside from the measurement issue of the SART, this may have real-world implications as text-speak becomes more common in daily life and work place settings. Indeed, digital text communication has had profound effects on civilian and military occupations (Cummings, 2004). Individuals commonly employ various methods of shortening words or phrases (text-speak) to achieve faster communication in a smaller amount of space (Crystal, 2008; Head et al., 2011). Although production of text-speak is thought of as effortless and fast, comprehension of text-speak does demand cognitive resources (Knott et al., 2006; Perea et al., 2009). This increased cognitive cost could even be deadly due to the lack of text-speak standardization (Turkoski, 2009). If a frequent text-user is highly proficient in processing and production of text-speak, it could induce a speed-oriented response strategy which could be problematic. Conversely, individuals who are not proficient with text-speak, may respond much slower to text-speak due to the cognitive cost of processing text-speak and slowness to respond may also have deleterious consequences. Additionally, no user is likely to be more proficient with text-speak relative to correctly written language which could induce error, especially with time-on-task.

Summary and Conclusion. In Chapter 4, two studies were conducted to investigate a theoretical interpretation of the SART and the cognitive cost that text-speak places on the reader as a function of time-on-task. Interestingly, the cognitive cost occurred even with a small stimuli list that was repeatedly shown. The text-speak questionnaire developed in Chapter 2 was able to show individual differences of willingness to use text-speak factor and behavioural results. Thus far, only one type of text-speak representation has been investigated (i.e., subsetting). Therefore, in the next chapter (Chapter 5), a larger variety of text-speak representations are investigated in a dual-task paradigm to determine whether reading text-speak impairs performance on a secondary task and further to elucidate the cognitive cost of processing other forms of text-speak.

CHAPTER 5

Text-speak processing impairs tactile location[4]

5.1 Abstract

Dual task experiments have highlighted that driving while having a conversation on a cell phone can have negative impacts on driving (Strayer & Drews, 2007). It has also been noted that this negative impact is greater when reading a text-message (Lee, 2007). Commonly used in text-messaging are shortening devices collectively known as text-speak (e.g.,**Ys I wll ttyl 2nite**, Yes I will talk to you later tonight). To the authors' knowledge, there has been no investigation into the potential negative impacts of reading text-speak on concurrent performance on other tasks. Forty participants read a correctly spelled story and a story presented in text-speak while concurrently monitoring for a vibration around their waist. Slower reaction times and fewer correct vibration detections occurred while reading text-speak than while reading a correctly spelled story. The results suggest that reading text-speak imposes greater cognitive load than reading correctly spelled text. These findings suggest that the negative impact of text messaging on driving may be compounded by the messages being in text-speak, instead of orthographically correct text.

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5.2 Introduction

A driver of a vehicle today is provided with an array of new technologies not seen in past generations. These include music and DVD players, global positioning systems and interactive communication devices such as cell phones. Although these new technologies afford the driver entertainment and convenience, they come at a cost. Physical operation of these technologies and holding a conversation have negative impacts on driving (e.g., Briem & Hedman, 1995; Brookhuis, De Vries, & De Waard, 1991; Hatfield & Chamberlain, 2005; McEvoy et al., 2005; Strayer, Drews, & Johnston, 2003; Tsimhoni, Smith, & Green, 2004). Talking on a cell phone is cognitively demanding, which can cause a form of inattentional blindness (Strayer & Drews, 2007). One consequence of involvement in conversation with an absent person is impaired awareness of important features of the driving environment: drivers miss critical signals (e.g., break lights or road signs) which can have dire consequences (Strayer, Drews, & Johnston, 2003; Strayer & Johnston, 2001). This may appear surprising because the acts of listening and speaking do not themselves involve the eyes or looking. Demanding cognitive activities appear to impair our ability to respond to important signals regardless of the sensory modality involved. Undoubtedly, talking on a cell phone has detrimental effects on driving ability (Strayer, Drews, & Crouch, 2006). However, other forms of distraction such as text messaging have been found to be even more distracting (Lee, 2007).

Text messaging evokes competition for resources between visual, manual, and cognitive processing (Head et al., 2011; Knott et al., 2006; Hosking & Young, 2009). Indeed, reading and responding to a text message is visually demanding and causes drivers to take their eyes off the road, which can have negative consequences (Hosking & Young, 2009; Lansdown, 2001; Wierwille & Tijerina, 1998). Moreover, the physical demand of key presses requires the driver to take one or both hands off the steering wheel, which is also dangerous (e.g., Reed & Green, 1999). Collectively, these studies indicate that text messaging is visually and physically demanding; however, they do not examine the possible central cognitive demands involved in processing text messages.

Maintaining attention is subject to a finite amount of mental resources (Navon & Gopher, 1979; Helton & Russell, 2011). Multiple resource theory (MRT) proposes that different pools of mental resources exist and are modality-specific (Kantowitz & Knight, 1976; Wickens, 1976, 1984, 2002). Thus, if an individual is presented with two stimuli in different modalities (e.g., visual and auditory) there should be less resource drain because they do not overlap (Wickens, 2008). Conceivably, this modality-specific processing is likely due to neuro-cortical specificity. Indeed, behavioural and neurophysiological studies have highlighted that tactile, word, and spatial processing occur in different cortical regions of the brain (Fiez & Petersen, 1998; Giabbiconi, Trujillo-Barreto, Goldberg, Perfetti, & Schneider, 2006; Karnath, Feber, & Himmelback, 2001; Martinovic, Gruber, & Müller, 2007; Peterson, Fox, Posner, Mintun, & Raichle, 1988; Price, 2000; Price, Wise, & Frackowiak, 1996; Pugh et al., 1996; Snyder, Abdullaev, Posner, & Raichle, 1995; Turkeltaub, Eden, Jones, & Zeffiro, 2002; Vandenberghe, Nobre, & Price, 2002). Nevertheless, cognitive task demand or 'mental workload' may have modulating effects on resource allocation (Wickens, 2008).

Given limited space or time to convey a message, people often incorporate shortening techniques to present meaningful content with less bits of information. For example, people use subsets (**txt,** text), shortcuts (**gr8**, great), phonetic respellings (**cya**, see you) and acrostics (**ttyl**, talk to you later) to convey messages in a shorter amount of time and space. Collectively, these shortening techniques above are known as text-speak (see Kul, 2007 for further examples). For individuals who are literate, word recognition is automatic (Stroop, 1935), and captures attention (Johnston et al., 1990). Conversely, prior research has established that presenting words in text-speak (e.g., **ys I wll ttyl 2nite**, yes I will talk to you later tonight) is not as automatic and does not capture attention as efficiently as correctly spelled words (Head, Russell, Dorahy, Neumann, & Helton, 2011). Additionally, text-speak words are less semantically meaningful (Head, Helton, Neumann, Russell, & Shears, 2011), and are more difficult to relate to sentence context (Head et al., 2013) than orthographically correct words. Collectively, text-speak appears to induce greater mental workload than correctly spelled words.

In the current investigation, we focused on the processing of text-speak stories, in contrast to correctly spelled stories, while participants concurrently monitored for vibrations in a secondary task. Although our design does not examine driving performance, it allows us to isolate the effects of text-speak cognitive processing from text messaging's visual and motor demands in a controlled setting. As alluded to above, monitoring vibrations on the body and reading text are non-overlapping modalities and should be processed by different cortical brain regions. Thus, according to Wicken's multiple resources theory (Wickens, 2008), performance decrements (increased reaction times, decreased accuracy, or both) should be attributed to the consequences of shared higher-level cognitive resources (those central or executive processing resources shared across modalities).

Does reading text-speak stories produce more errors in a secondary task relative to reading correctly spelled stories? The following predictions are tested: First, compared with a single task vibration detection situation, detection of tactile vibrations will fall and detection times will increase in a dual task where participants simultaneously read a passage for meaning. Second, there will be a greater decline in detection performance when reading text-speak passages compared to reading correctly spelled passages. Third, following Head et al. (2011), the disruptive effects on vibration detection when reading text-speak will be less pronounced in participants who report more willingness to use text-speak. Finally, it is predicted that reading text-speak will result in lower reading comprehension scores than correctly spelled stories.

5.3 Methods

Participants. Forty right-handed University of Canterbury students (26 women and 14 men, *M* age = 21 yrs, *SD* = 5 yrs) participated in the experiment for course credit. All participants were native English speakers and had normal or corrected to normal vision.

Tactile stimuli. Presentation and timing of visual and tactile stimuli and response accuracy and timing were achieved using E-prime Professional 2.0 (Schneider, Eschman, & Zuccolotto, 2002). For the vibration task, participant responses were measured to millisecond precision by a serial response mouse. Each participant was outfitted with a tactile stimulation belt that was worn around their abdomen (see Figure 5.1). The adjustable elastic belt consisted of eight EAI model C2 Tactors (Engineering Acoustics, Inc, Winter Park, FL) although only two tactors were used. The 17g (30mm diameter by 7.9mm height) tactors utilize a center-surround design that enables a 7.6mm plunger-like contactor to generate precise localized stimulation (see Figure 5.2). This provided sinusoidal vibrations to the skin at 250 Hz.

Figure 5.1. *Example of participant fitted with tactor belt.*

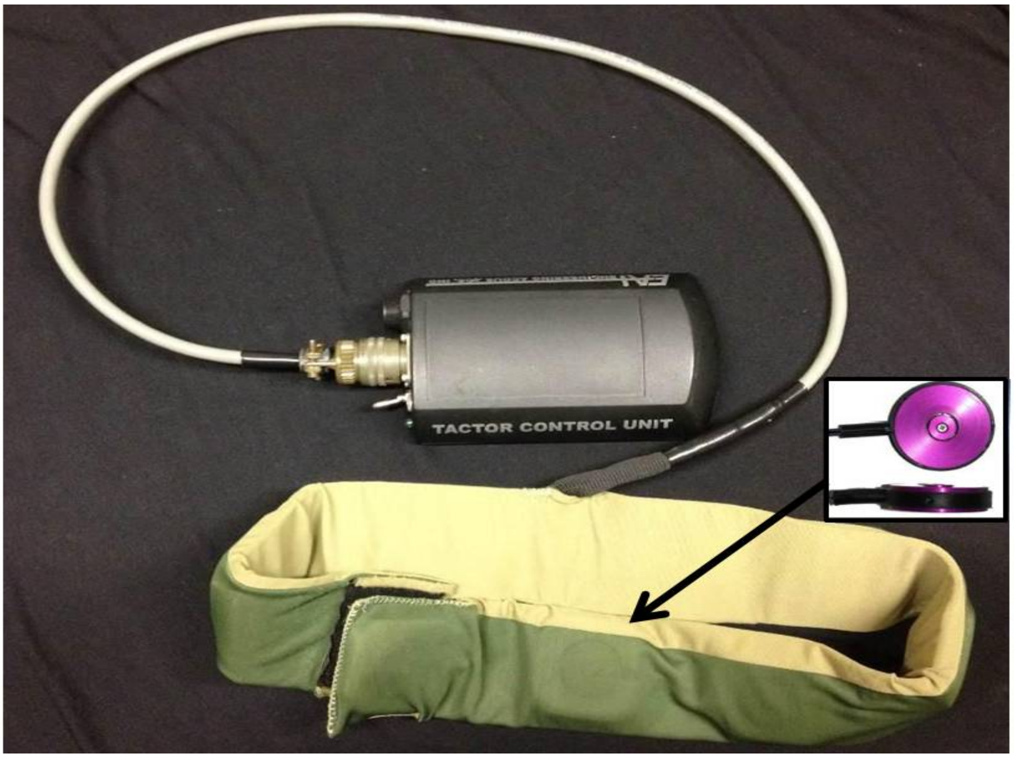

Figure 5.2. *Display of tactor belt and plunger contactor used in the study.*

Reading passages. Two stories[5] were selected and matched for word length (755 words) and level of reading difficulty (Flesch, 1948). Subsequent text-speak versions of each story were created by substituting correctly spelled word forms (e.g., *tonight*) with text-speak versions (e.g., *2nite*) when possible. Text-speak stories were controlled for number of substitutions and shortening techniques (Chaudhury et al., 2007; Crystal, 2008; Head et al., 2011; Plester, Wood, & Bell, 2008). On average for both stories, 60% of the words were text-speak representations and 40% were correctly spelled. The 40% correctly spelled accounted mostly for conjunctions (e.g., but, or, & yet) and articles (e.g., a, an, & the). Given that the participants were from New Zealand, we used text-speak representations from the New Zealand text-speak norm database (Head et al., 2013).

Text-speak questionnaire. The text-speak questionnaire (Head et al., 2011) is a 9 item self-report questionnaire that consists of 3 factors: willingness to use text-speak, text messaging experience, and preference for use text messaging. This questionnaire has been used in previous studies and has successfully correlated text-speak willingness with behavioural performance (Head et al., 2011; Head et al., 2012). The willingness to use text speak factor consists of 3 items directly addressing self-reported experiences of using text-speak in texting: (1) I always use acrostics (got to go-gtg) when text messaging, (2) I always use subsetting (Text-Txt) when I send a text message) and (3) I always use predictive text when I use my cell phone (reverse scored). This is a separate text-speak specific aspect of texting, than for example, overall texting frequency.

Procedure. Upon arrival, participants were given an overview of the study and requested to read and sign an informed consent form. Participants were screened during the practice trial for tactile sensitivity which resulted in one participant being excluded from the study. All participants wore a 198 g 100% black cotton t-shirt to ensure standardization of the material between the tactors and the skin (Brill, 2007). The vibrotactile belt was worn

[5] Stories were selected and augmented from http://legacy.lclark.edu/~krauss/toppicks/reading.html?

approximately 25mm above the navel. A circumference measurement around each participant was taken on the abdominal plane above the iliac crest. This measurement allowed us to place the tactors at approximately equal lateral distances from the naval midline on the left and right side of the body (Cholewiak, Brill, & Schwab, 2004; Brill, 2007).

Participants were seated 50 cm in front of a 32.5 x 24 cm CRT Compaq S720 monitor at approximately eye level. Their heads were not restrained in any way. For the vibration task participants were instructed to press the left button of the serial mouse with the index finger of their right hand whenever a vibration occurred on the left side of their body and with the middle finger of their right hand to vibrations occurring on the right side of their body. They were instructed to make responses as quickly as they could without making errors. The 250 Hz vibrations lasted 100 ms and were followed by a 1000 ms interval during which responses were accepted and recorded. Responses after the 1000 ms interval were recorded as misses. During single task vibration only trials (VOT) and dual task conditions, vibrations occurred at the rate of 55 stimuli per minute and continued for 6.28 minutes.

In dual task conditions participants were informed that they needed to read and comprehend a story while at the same time responding to vibrations that occurred on the left or right side of their torsos. They were also informed that they would be tested on their understanding of the story at a later time. The story passages were presented using the Rapid Serial Visual Presentation (RSVP) method that is commonly used in reading research (Bernard, Chaparro, & Russell, 2001; Juola et al., 1995; Rahman & Mutter, 1999). Words or text-speak abbreviations were presented one at a time in the centre of the screen at the rate of one item every 500 ms (i.e.,120 words per minute). This presentation rate was chosen because extensive pilot work revealed this was the minimum rate necessary for comprehension of text-speak, which is known to take longer to read than normal text (Salvucci, 2001; Reilly, & Radach 2006; Knott et al., 2007; Head et al., 2011). RSVP was favoured because it prevents the influence of spatial attention shifts between visual and tactile modalities (Spence, Pavani, & Driver, 2004). During dual task trials the start time for the first vibration stimulus was varied so that the vibrations did not coincide with the onset of words or text-speak items. For example, as the first word was being shown (500 ms), the vibration could either commence at 100 ms, 200 ms, or 300 ms during the first word presentation. To accomplish this E-prime randomly assigned each individual to one of 3 delays (e.g., 100 ms, 200 ms, 300 ms) on the onset of each dual task. This was done to discourage participants from using word onset from the RSVP task as a visual cue for the initial vibration occurrence and to stagger their appearance throughout the task. The tactile task across participants; however, occurred with a constant inter-stimulus interval (ISI).

Participants completed one VOT block followed by two dual task blocks (reading with intermittent concurrent vibration) and then a second block of VOT trials. Prior to each experimental block, participants performed VOT trials for approximately one minute and were given accuracy feedback. They also completed a 2 min long dual reading and vibration detection practice session to familiarize them with the RSVP method of presentation and the requirements of the dual task. Text-speak and correctly spelled dual tasks were preceded with task appropriate practice. Participants received visual accuracy feedback during the dual task practice trials only. Participants were instructed to read for comprehension and respond to vibrations as fast and accurately as possible. The entire experimental session lasted approximately 40 minutes.

Design. The experiment entailed a within-subject design. Each participant was presented with VOT pre and post dual task conditions. Each participant completed a dual task with a story presented as text-speak and correctly spelled. The order of stories and whether they were presented as text-speak or correctly spelled were counterbalanced between participants.

5.4 Results

Reaction time. Response times greater than 1000 ms and less than 200 ms were excluded from reaction time analysis to reduce the likelihood of outliers as recommended by Ratcliff (1993). Response times for the first and second VOT blocks were averaged. A one-way repeated measure ANOVA on correct responses was conducted to compare reaction times for the three conditions: VOT, dual task with correctly spelled words and dual task with text-speak. There was a significant overall effect, $F(2, 78) = 11.14$, $p < .001$, $\eta^2_p = .22$ (see Figure 5.3). Orthogonal contrasts (Keppel & Zedeck, 2001) indicated that the location responses were faster for single task VOT trials (M = 278 ms; SD = 55.9) than dual task reading and vibration conditions, $F(1, 39) = 13.43$, $p = .001$, $\eta^2_p = .26$. Further, location responses were faster when reading correctly spelled (M = 311; SD = 63.6) than text-speak passages (M = 322; SD = 64.9), $F(1, 39) = 4.15$, $p = .05$, $\eta^2_p = .01$.

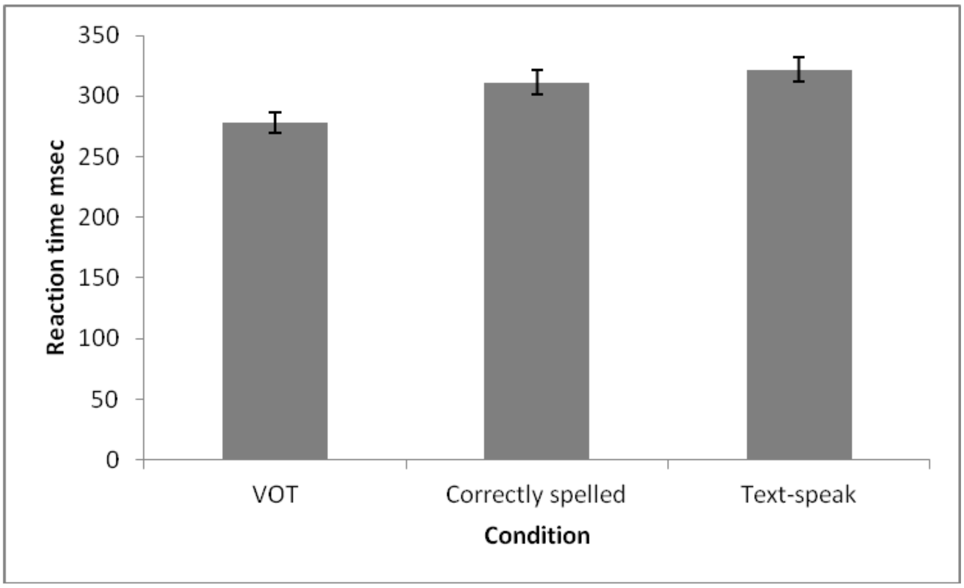

Figure 5.3. Reaction times for correct responses for VOT, correctly spelled, and text-speak conditions; error bars depict standard error of the mean.

Correct vibration responses. Probability of correct vibration location responses for the three conditions are presented in Figure 5.4. A one-way repeated measures ANOVA was conducted on arcsin transformed (Kirk, 1995; Maxwell & Delaney, 2004) proportion correct vibration responses for the VOT, and two dual task conditions. Arcsin transformation was chosen due to the data being skewed. The overall effect was significant, $F(2,78) = 52.88$, $p < .001$, $\eta^2_p = .58$. Orthogonal contrasts indicated that the proportion of correct vibration responses was significantly higher for the VOT ($M = .94$; $SD = .06$) than dual task conditions, $F(1, 39) = 81.91$, $p < .001$, $\eta^2_p = .68$, and that the proportion of correct vibration responses was significantly greater when reading correctly spelled passages ($M = .88$; $SD = .08$) than text-speak passages ($M = .86$; $SD = .11$), $F(1, 39) = 7.78$, $p = .008$, $\eta^2_p = .17$.

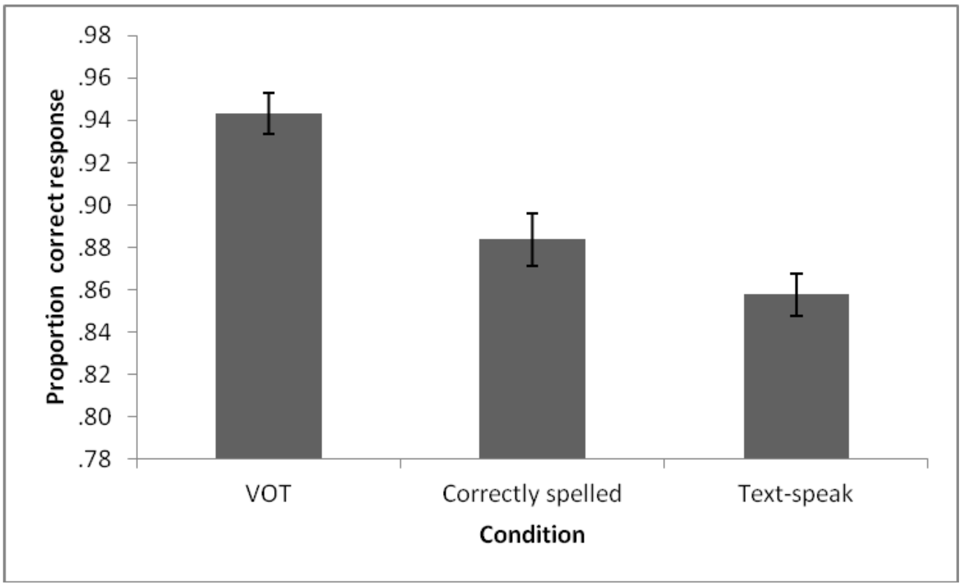

Figure 5.4. Proportion of correct responses for baseline, correctly spelled, and text-speak conditions; error bars depict standard error of the mean.

Missed responses. The proportions of occasions where vibration location responses did not occur within the 1000 ms response window are presented in Figure 5.5. A one-way repeated measures ANOVA was conducted on arcsin transformed missed responses for the VOT, and dual task conditions. There was a significant overall effect, $F(2,78) = 26.81$, $p <$

.001 η^2_p =.41. Orthogonal contrasts indicated that failure to respond to vibrations occurred less often in the VOT condition (M = .02; SD = .03) than in the dual task conditions (M = .07; SD = .08), $F(1, 39) = 42.94$, $p < .001$, η^2_p = .524. However, vibrations were missed equally when reading correctly spelled stories and those in text-speak (see Figure 5.5).

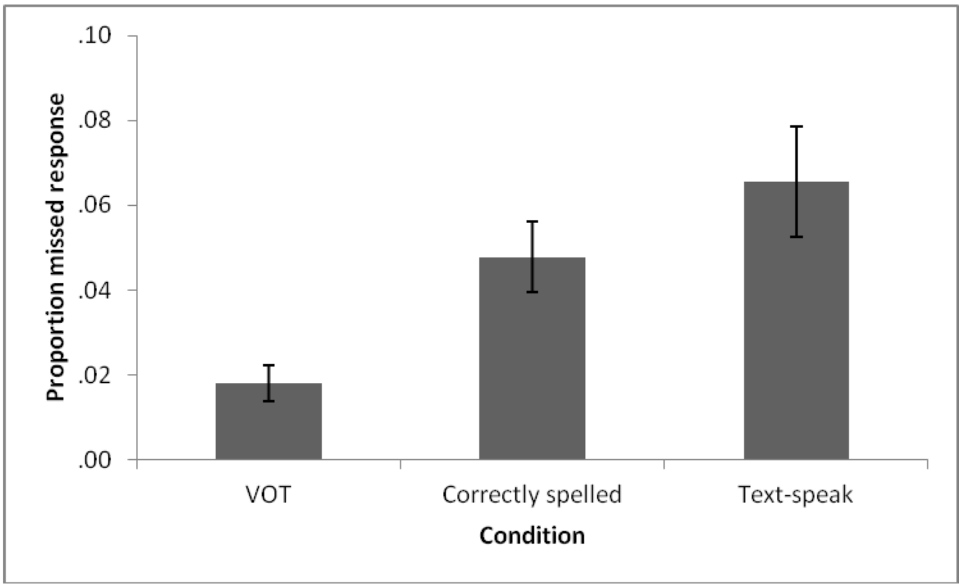

Figure 5.5. Proportion of missed responses for VOT, correctly spelled, and text-speak conditions; error bars depict standard error of the mean.

Relationship between Performance Metrics and Self-reported Text Experience. Gender and age did not yield any significant correlations with participants' accuracy or reaction time in either of the dual tasks. We correlated each participant's correct response time in the text-speak dual task with the willingness to use text-speak factor derived from the questionnaire. This correlation was negative and statistically significant $r(39) = -.313$, p =.05). Thus, as self-reported willingness to use text-speak increases response time decreases. To verify that those who report being more willing to use text-speak were not just generally faster overall we correlated those participants' correct reaction time with the correctly spelled dual task, but it was statistically non-significant ($r(39) = -.203$, p = .21). No other correlations with the behavioural performance data were significant and thus are not reported.

Reading comprehension assessment. Participants completed a 10-item true/false reading comprehension assessment for the correctly spelled and text-speak stories. The proportion correct was calculated for each assessment and was then arcsine transformed as recommended (Kirk, 1995; Maxwell & Delaney, 2004) prior to analysis (see Figure 5.6). A *t*-test revealed no difference in reading comprehension scores for correctly spelled stories (M = .84; SD = 2.34) and stories written in text-speak (M = .80; SD = 2.62), $t(39) = 1.30$, $p = .23$.

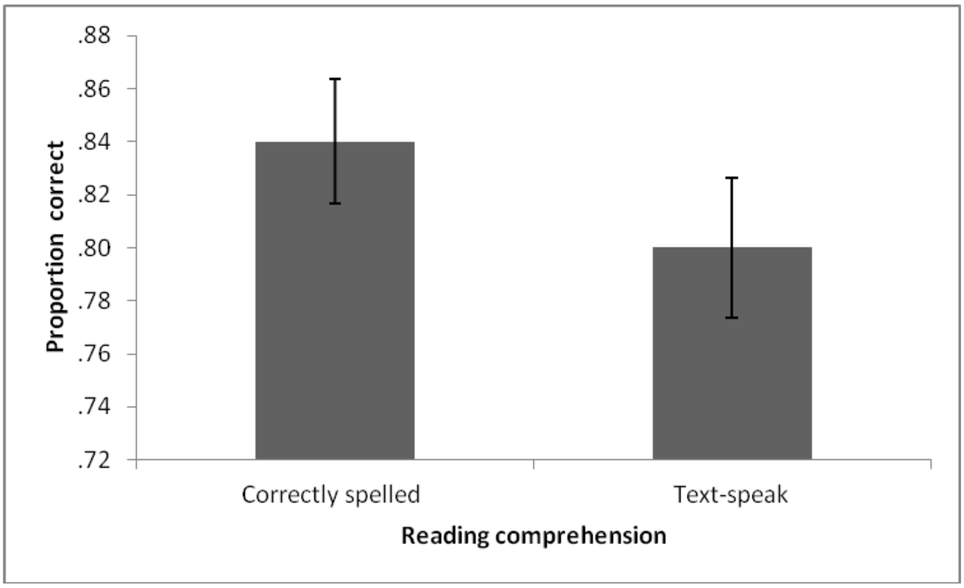

Figure 5.6. Proportion correct for comprehension assessment for correctly spelled and text-speak conditions; error bars depict standard error of the mean.

5.5 Discussion

This study examined whether reading stories presented in text-speak is more resource demanding than reading the same stories correctly spelled. Participants completed a dual task where they reported the laterality of a brief vibration on their torso while concurrently reading a story presented as text-speak or as correctly spelled words. Compared to a single task vibration only condition, accuracy and speed of reporting the location of vibrations was considerably reduced when participants concurrently read a story. Importantly in the present context, speed and accuracy of vibration location responses was impaired more when reading text-speak compared to correctly spelled versions of the same stories. Crucially, the dual task employed was sensitive in distinguishing differential cognitive demands between correctly spelled and text-speak stories presented in the dual tasks. The text-speak questionnaire was successful in showing that those with greater self-reported willingness to use text-speak were more accurate and faster to respond to tactile vibrations when comprehending text-speak messages but not when comprehending correctly spelled messages..

Analogous to Strayer and Drews' (2007) findings, a participant engaged in two tasks of non-overlapping modalities (visual and tactile) can still undergo a form of inattentional blindness, resulting in missed critical signals. Further, our results show that a form of inattentional blindness to critical signals is not modality specific to auditory stimuli paired with visual, but also when tactile stimuli are paired with visual. Maintaining attention is thought to be subject to a limited amount of resources (Navon & Gopher, 1979; Green & Helton, 2011; Helton & Russell, 2011). Within our study we have two tasks (reading and tactile monitoring) competing for attention resources. As stated above, word recognition demands attention (Stroop, 1935; Johnson et al., 1991). Therefore, missed critical signals within the tactile portion of the dual task can be attributed to the appropriation of mental resources to the reading task. Indeed, this could be due to the reading task being more contextually engaging than the tactile task.

According to the MRT, multiple resource pools exist and are modality-specific for processing information. Therefore, processing two stimuli of different modalities should cause less resource depletion relative to processing the same stimuli within the same modality. Participants' performance during the dual task was significantly hindered compared to the VOT, suggesting that the activities of reading and monitoring for vibrations are competing for the same resource pool. However, since they are in different sensory modalities (visual vs. tactile) and one is verbal (reading) and the other spatial (vibration location) the shared resources are presumably at a higher cognitive level (see Helton &

Russell, 2011). Wickens (2008) suggests if mental workload is high, then greater mental resource depletion can occur. Indeed, this may be because the task is novel. It has been noted that completing a novel task can increase mental workload (Hancock & Meshkati, 1998). For those who are literate, reading is not considered a novel task; however, monitoring and responding to a vibration is likely to be novel for most participants. The reading and vibration task coupled into a combined endeavour appears to increase mental workload, which thus increased mental resource demand.

The vibration detection task and the reading task were in separate sensory modalities, which should interfere less than two tasks in the same modality (for example, driving and texting). The vibration detection task was spatial, and the reading task was verbal. These two tasks should interfere less than two spatial tasks (for example, driving and orienting on a map). The vibration detection task required a simple manual response and the reading task required no manual response (not until later with the reading comprehension test). These two tasks should interfere less than two tasks requiring a manual response (like driving and texting). The vibration task was relatively simple, two alternative forced choice, with clear response mapping (right to right, left to left) and a constant ISI. Even though every effort was taken to minimize the interference effect between the two tasks, there was still greater dual-task interference for the text-speak than the orthographically correct text task. We expect that even though the size of our effect is small in this study, the additional demand of text-speak processing could be a contributory factor in a snowballing effect and thus, larger effect, in a more realistic scenario where the two tasks may overlap greater in resource demands. This requires further research.

Text-speak representation allows an individual to present a word in a shorter amount of time and space (Head et al., 2011). However, if the reader of the word is less confident about using text-speak, additional mental workload may be needed (Head, Helton et al., 2011; Head, Russell et al., 2011). Indeed, the negative correlation between the willingness to use text-speak factor and reaction time suggests that if an individual is more willing to use text-speak, then less mental workload is placed on that reader, which equates to less mental resource demand.

Interestingly, our reading comprehension scores failed to show a statistically significant negative impact of reading a story in text-speak in comparison to reading a correctly spelled story. To insure that participants could comprehend text-speak words, we used longer word durations based on piloting. As pointed out by an anonymous reviewer, slower word presentation may have oversimplified the task, which may explain why participants did not differ on the comprehension test. Indeed, a faster word presentation may better demonstrate the cost of processing text-speak relative to correctly spelled passages. Nevertheless, the behavioural data did show a performance decrement to vibration monitoring when participants were reading text-speak. Thus, the higher than expected reading comprehension scores for the text-speak story can be attributed to a performance comprehension trade-off (see Head et al., 2011). In other words, in order for someone to achieve the higher than expected reading comprehension scores for text-speak, reaction time and accuracy are sacrificed on the vibration task to facilitate comprehension of the story.

This study demonstrated that presenting stimuli in different modalities induces elevated cognitive resource demands. Although our study does not include assessments of driving performance per se, it nevertheless has implications for any tasks combined with reading text-speak. We showed in a controlled setting that reading stories in text-speak increases performance decrements relative to reading correctly spelled stories. The applied implication of the results is that reading text messages while driving is extremely dangerous in its own right; however, this danger can be compounded further if the driver is reading messages in text-speak. Indeed, processing non-overlapping modalities (tactile vs. visual) should produce relatively less interference compared to processing overlapping modalities. Thus one would expect far greater interference if trying to watch the road and read a text message while driving. Further research is needed to investigate the effects of text-speak processing in other settings such as driving to better understand the potential cost of reading text-speak while performing other tasks.

Summary and Conclusion. In Chapter 5, the cognitive cost of processing text-speak was investigated by examining whether reading a story presented in text-speak versus correctly spelled affected performance on a secondary task. The results revealed that reading text-speak significantly impairs performance on a secondary task which is indicative of text-speak requiring additional mental resources to process. The text-speak questionnaire once again revealed that individual differences (i.e., willingness to use text-speak) can influence performance. As briefly mentioned in Chapter 5, neuro-cortical specificity exists with regard to areas of the brain engaged in processing specific types of information (e.g., occipital lobe and visual processing). In the next chapter, the principle of neuro-cortical specificity is applied grossly to the left and right hemisphere of the brain in an attempt to broadly target language processing (Beeman & Chiarello, 1998).Therefore, in Chapter 6, a divided visual field experiment is used to investigate how the left and right hemisphere of the brain process correctly spelled versus text-speak target word probes.

CHAPTER 6

Novel word processing[6]

6.1 Abstract

Individuals who text messages often shorten words by eliminating internal letters (e.g., climate, clmte). Although these novel representations (i.e., subset word forms) are not true words, sentence context may prime semantic activation. We hypothesized that if participants are presented with a context sentence prime containing a subset-form target word, then participants' performance should increase when the stimulus is presented to the left-visual field/right hemisphere (LVF/RH) due to the RH being less reliant on correct orthography than the left hemisphere (LH). We also hypothesized that participants' bias toward processing novel stimuli is a function of visual field/hemisphere presentation. The results supported the hypothesis, when participants were shown subset word forms in the LVF/RH their accuracy was significantly greater relative to the RVF/LH. Additionally, signal detection theory was applied to the results and substantiated the findings that participants' contrasting bias towards processing subset and orthographically correct words is a function of visual field/hemisphere presentation.

[6] Published paper: Head, J., Shears, C., Neumann, E., & Helton, W. S. (2013). Novel word processing. *American Journal of Psychology*, *126*(3), 323-333.

6.2 Introduction

The introduction of modern digital communication technologies such as electronic mail (i.e., e-mail), online instant messaging and text messaging greatly increases the use and invention of novel language. Indeed, this new technology is influencing both civilian and military communication (e.g., Knott et al., 2006; Lesch & Hancock, 2004; Turkoski, 2009). Recently there has been an increase in the use of text messaging, which enables an individual to send an instant written text. A shortcoming of text messaging is the length of time needed to construct words and sentences. Contingent on the phone, the process of forming words and sentences on a cell phone may require an individual to search the keypad for the number that corresponds to the desired letters (e.g., the number 2 contains letters, A, B, and C). This makes constructing simple words and sentences time consuming and awkward, even to an experienced user (Crystal, 2008).

To shorten the time spent sending a message, cell phone users adopt various shortening techniques (e.g., acrostics, phonetic respellings and letter omission; see Kul, 2007 for additional examples). Although shortening techniques are word-like (Ganushchak, Krott, & Meyer, 2010) and allow individuals to convey messages more quickly (Knott et al., 2006), this may come at a cost. For example, eye tracking experiments demonstrate that participants reading text-speak have increased fixation durations on each word and overall increased reading latency relative to reading sentences composed of correctly spelled words (Ganushchak, Krott, Frisson, & Meyer, 2011; Perea, Acha, & Carreiras, 2009). Increased fixations and increased reading latencies denote increased cognitive demand on the reader (Reilly & Radach, 2006). Although reading correctly spelled words is generally automatic (Stroop, 1935), when words are presented in text-speak, additional processing time may be required to achieve word activation (Head, Helton, Russell, & Neumann, 2012).

The process of omitting letters of a word has been defined as subset word form, while non-altered words are classed as the identity form (e.g., Assche & Grainger, 2006; Head, Helton, Neumann, Russell, & Shears, 2011; Head, Russell, Dorahy, Neumann, & Helton, 2011). The literature addressing subset word representation has been limited to unconscious masked priming paradigms (e.g., Assche & Grainger, 2006; Head, Helton et al., 2011; Perea & Gomez, 2010), sustained attention (Head, Russell et al. 2012) and dual-tasks (Head, Helton, Russell, & Neumann, 2012). Researchers, moreover, have shown that participants retain the ability to derive word meaning, even when the word is orthographically incorrect (e.g., Chang & Turvey, 2003; Christianson, Johnson & Rayner 2005; Head, Helton et al., 2011). Collectively, these studies have addressed how individuals process subset words. However, each study only utilized central presentation and thus neglected addressing specifically how each hemisphere may contribute to processing novel subset language representations.

Although both hemispheres of the human brain appear to be symmetrically similar, they differ in topographical features (e.g., Sylvian fissure and Yakovlevian anticlockwise torque; LeMay, 1979) and have differential responses to neurotransmitter exposure (Glick, Ross, & Hough, 1982). These hemispheric asymmetries are further evident from behavioural studies measuring human motor behavioural responses to visual stimuli such as words (see Hellige, 2001 for other examples of asymmetries).

Researchers have explored the differences in language processing between the left (LH) and right hemispheres (RH) utilizing the divided visual field (DVF) paradigm for decades (Beeman & Chiarello, 1998). There are at least three criteria employed in DVF methodologies that ensure the reliability of identifying and measuring hemispheric differences (Beeman & Chiarello, 1998). First, a central fixation point is visually presented on all trials and participants are instructed to maintain focus on the central fixation throughout the experiment. In many experiments, this fixation point is further emphasized by a 'flicker' which recaptures participants' attention before the actual response is made (Chiarello, et al., 2006). Second, DVF methodologies employ the standard use of either head or chin rests, usually set 60 – 70 cm from the monitor, to stabilize the participants head and maintain central fixation throughout the experiment. And third, visual angle or eccentricity of target presentation is controlled for all target stimuli such that lateralization of presentation location combined with target duration (usually less than 300 ms) ensures processing by the intended hemisphere (Chiarello, et al., 2006).

From these DVF studies, the LH dominance for language comprehension and production has been well documented (see Chiarello, Liu, & Shears, 2001). However, a growing body of evidence has also established that the RH does play a vital role in language processing. Behavioural studies in inference processing, maintenance of context, limited single concrete word identification, and overall comprehension of language has supported the role of the RH (Beeman & Chiarello, 1998; Chiarello, Shears, Liu, & Kacinik, 2004). Physiological evidence from acquired brain injury or left hemispherectomy studies has also illustrated that the RH plays a role in humour, emotional valence, and language comprehension (e.g., Beeman 1993; Borod, Bloom, & Haywood, 1998; Cheang & Pell, 2006; Telfeian, Berqvist, Danielak, Simon, & Duhaime, 2002).

Indeed, recent theorizing about brain lateralization would suggest that sentence primes followed by subset target words are better processed in the RH. Beeman, Friedman, Grafman, and Perez (1994), for example, proposed the Coarse Semantic Coding theory, which stipulates that the RH has a broad but weak area of semantic activation. Conversely, the theory postulates that the LH activation is stronger but confined to a smaller area of semantic activation. Beeman, et al. (1994) reported results which revealed that weakly related primes are processed more efficiently in the RH than the LH. When priming stimuli were weakly related to the target words, participants were better able to make the connection between the prime and target when it was presented to the RH.

If sentences provide adequate context for recognition of target words, then novel word forms presented to a participant's RH may benefit from this context prime in its ability to infer a meaningful novel word form relative to presentation to the LH. Indeed, Chiarello, et al. (2001), have indicated a difference between the hemispheres' reliance on context. Research suggests that the RH is able to sustain weakly associated sentence contexts to access target word meanings (Beeman, Bowden, & Gernsbacher, 2000). Thus, the RH may have an increased ability relative to the LH to infer a subset word's semantic meaning given a prior sentence prime.

Federmeier and Kutas (2002) have suggested that a stimulus presented to the LH is processed by means of top-down processing and in categorization tasks, both for words and pictures, tends to be predictive of subsequent stimuli. Thus, in the case of a sentence prime, a participant might be more likely to predict an identity form completion (i.e., target word) if presented to the LH. Indeed, novel subset forms presented to the LH may be responded to more slowly and less accurately because the novel word form fails to meet the expected identity word. Alternatively, this same information presented to the RH may result in the individual taking a wait and see perspective, which may actually be quicker and more accurate at identifying novel subset forms. The main assumptions of both of these perspectives are that the LH and RH work in parallel to process sentence information, but they perform different operations or are biased for different kinds of processing (e.g., division of labour).

Further support for this division of labour comes from a recent transcranial direct current stimulation (tDCS) study. Chi and Snyder (2011) had participants complete a cognitive task while stimulating the RH and suppressing the LH using tDCS. For the cognitive task, participants were required to repeatedly complete trials in a matchstick arithmetic task that only required one "insight" on how to solve it. Generally, when participants complete repeated trials with one "insight" their performance is greatly hindered when presented with a new trial that requires a different solution method (Öllinger, Jones, & Knoblich, 2008). For those who did not receive tDCS, only 20% were able to solve the new insight problem. However, participants that received the tDCS were 3 times more likely to solve the problem. The Chi and Snyder findings indicate that the RH excels at processing atypical novel stimuli.

By integrating the coarse coding theory of Beeman and associates and Federmeier's and Kutas' theories regarding top-down and bottom-up processing, we expect differences in response bias and discriminability for identity and subset forms as a function of visual field/hemisphere presentation. When preceded with sentence primes, we predict greater overall discriminability (signal detection sensitivity metric A') and lower reaction times (RT) for subsequently presented identity words than for subset words. However, there will be differences in performance, both discriminability and reaction time, as a function of visual field/hemisphere presentation. Specifically, participant performance will be better when subset words are presented to the LVF/RH relative to when the subset words are presented to the RVF/LH. Identity word processing should be better in the RVF/LH. In regards to response biases, Mashal and Faust (2008) used signal detection theory in a recent laterality study and found that participants had more liberal response bias to metaphoric expressions when presented to the LVF/RH, whereas participants had the opposite response bias when the stimulus was shown to the RVF/LH. We suspect that participants will treat subset words in a manner similar to unfamiliar metaphoric expressions. With respect to bias (Green & Swets, 1974), we expect participants will be more liberal (more willing to respond positively) with their responses to identity words when presented to the RVF/LH relative to LVF/RH presentation, while participants' responses to subset words should be more liberal when shown to the LVF/RH. Essentially, participants will be more oriented to detect and select highly familiar identity words when presented to the RVF/LH compared to the LVF/RH, whereas participants will be more oriented to detect and select subset words when presented to the LVF/RH compared to the RVF/LH.

6.3 Method

Design. The experiment entailed a 2 word form: (identity vs. subset) x 2 visual field (LVF vs. RVF) within-participant factorial design with reaction times and accuracy for "yes" responses providing the measures of interest. Accuracy data was used within the signal detection analysis.

Participants. Sixty Chapman University undergraduates (54 females) provided informed consent to participate in this experiment. All participants were native English speaking with a mean age of 20.5, SD = 1.26, right handed, and had normal or corrected-to-normal vision. Handedness was measured by a 10-item preferences questionnaire (Oldfield, 1971). All participants that participated had the minimum criterion +.60 to participate.

Materials. The stimuli consisted of 81 sentence primes (72 experimental and 9 practice) which were followed by one of four target types: An identity word that related (i.e., semantically) to the sentence, or a subset form of that related identity word, an identity word that was unrelated (i.e., non-semantically) to the sentence or a subset form of the unrelated identity word (see Table 6.1). Unrelated identity and subset targets served as filler items to facilitate "no" responses. Identity words were the orthographically correct representations of the target words. Subset words consisted of 1, 2, or 3 non-adjacent omitted letters within the word (e.g., C_nt_xt,). Letters omitted included consonants and vowels. The positions of letters omitted were varied and counterbalanced between four lists. For example, List 1 had the example from *Table* 6.1 (The dog dug up the) with the related identity target (bone) and the (Flowers have a nice) with the unrelated subset target (socr). List 2 had the example from Table 6.1 (The dog dug up the) with the related subset target (bne) and the (Flowers have a nice) with the unrelated identity target (soccer). Thus a target word exemplar only occurred once per list. This design allowed us to measure the priming effect of context sentences for related identity targets relative to unrelated identity targets, and priming effects of context sentences for related subset targets relative to unrelated subset targets.

Table 6.1

Example of target probes presented in subset and correctly spelled analogue

Word form targets	**Subset**		**Identity**	
Sentence primes	**Related**	**Unrelated**	**Related**	**Unrelated**
The dog dug up the	bne	nght	bone	night
Flowers have a nice	sml	socr	smell	soccer
The student went to	clge	pymt	college	payment

Note: Related and unrelated describe the target word probe relationship with sentence prime.

To the authors' knowledge, there is no literature that stipulates acceptable cut-offs for measures of relatedness. Thus, an extensive norming procedure was conducted for all context sentences and target words (both subset and identity) to measure related and un-relatedness using a pencil and paper task. Fifty-six introductory psychology students, who were not included in the later study, completed a paper and pencil task based on a 5-point scale. Students were instructed to read the sentence and determine if the target word was appropriate to complete the sentence by circling a number on the 5-point scale (1 unrelated through 5 related). To insure that sentences and targets were strongly related, we limited our inclusion to targets receiving a score of 4 or greater ($x > 4.00$), $M = 4.51$, $SD = 0.34$.

Following the same procedure above, an additional sixteen participants were recruited to determine how related the unrelated identity and subset words were to preceding sentences (M = 1.5, SD = .94). Target identity words had an imageability M = 6.00, SD = 0.94, with a word frequency of M = 3.81, SD = 0.49 (Chiarello, Shears, & Lund, 1999). To date there is no established imageability and word frequency for subset target words. In a post hoc analysis we examined psycholinguistic properties of our stimuli (n-gram, word frequency, and neighbourhood density coefficients) to verify that our stimuli did not have psycholinguistic properties mediating our results. To test this, we first calculated the average reaction time and accuracy rate for each response to correctly spelled words and their subset counterpart for each participant. We then ran two separate regression analyses for correctly spelled and subset words to determine whether the psycholinguistic properties predicted reaction and accuracy. Both analyses failed to reach significance $p > .05$. Target word form (identity vs. subset) and visual field presentation were balanced across lists. Targets and sentence primes were presented in lower case Times New Roman 12 font (Ducrot & Grainger, 2007). Target words were presented subtended 0.55°- 0.70° of vertical visual angle and 0.80°- 2.15° of horizontal visual angle.

Procedure. Participants were seated in individual testing rooms where they provided informed consent, a history of their language experience, a handedness score, and a vision test. The computerized task followed, completed on Dell computers (38.5cm LCD screen size) and Direct RT software (Jarvis, 2006). Initially, “Please wait for instructions from the experimenter” was presented centrally on the screen, while the experimenter verbally explained the procedure. Participants were told the experiment would test the differences between the left and right hemisphere’s processing of language, and that they would be reading a simple English sentence followed by a single target word. Participants were instructed to decide whether the target word made sense given the context of the sentence just shown. They were instructed to rest their right hand on the numeric key pad with their index finger on the “0” and their middle finger on the “.” key in order to respond as quickly and accurately as possible. A paper template covered the numeric keypad with the exception of the “0” and “.” keys were labelled to specify that pressing the “0” indicated a “YES” response (i.e., target word makes sense with the sentence) and pressing the “.” indicated a “NO” response (i.e., target word does not make sense with the sentence). Participants were instructed to place their index finger as comfortably far away from the “.” as to reduce the likelihood of mistakenly touching the wrong key. Participants were also instructed to rest their head in a chinrest, which was positioned 62 cm away from the computer screen to help ensure that the participant was always attentive to the center of the screen (see Figure 6.1). Participants were instructed to keep their eyes focused on a plus sign in the center of the screen.

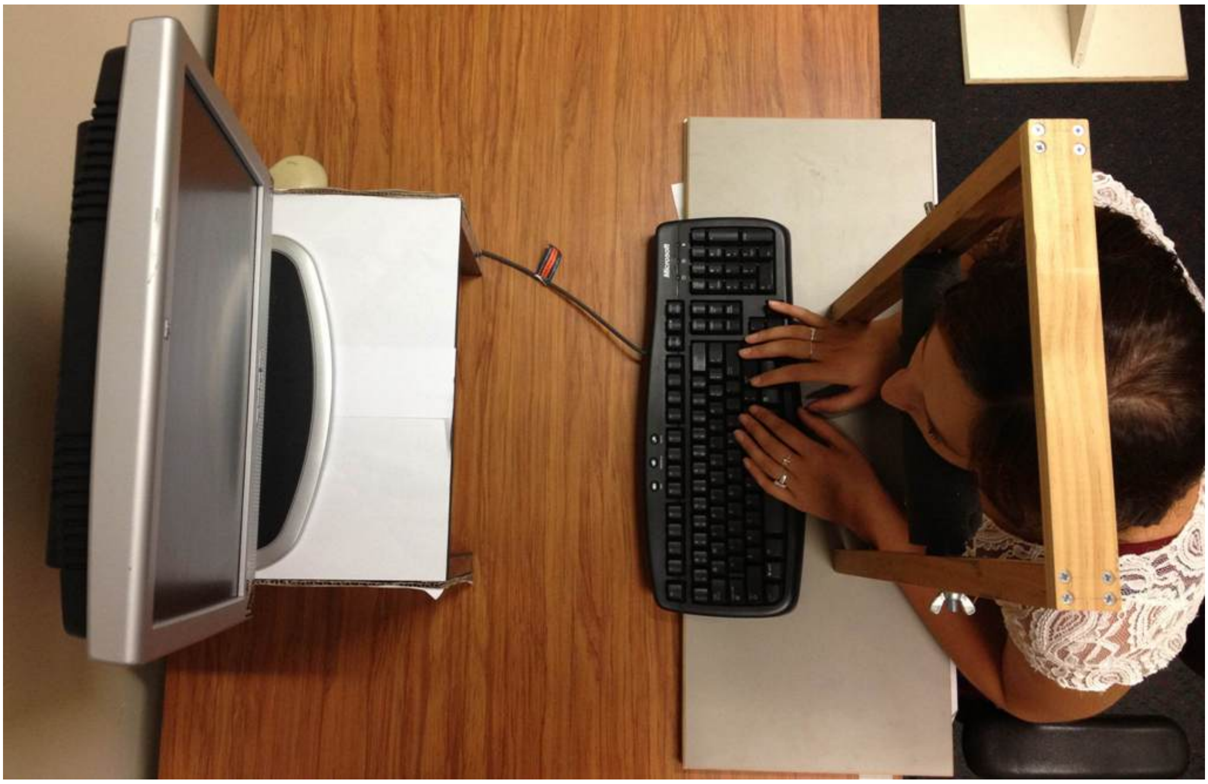

Figure 6.1. Example of participant using chin rest.

The experiment began when the participant pressed the space bar. The sentence prime appeared for 1200 ms. All of the sentences were centrally presented in Times New Roman 12pt font with normal capitalization and punctuation. After the sentence prime there was a 100 ms blank screen. Next a black plus appeared in the center of the screen for 200 ms followed by an overlapping red plus for 100 ms and then finally a black plus for 300 ms. Following the fixation point sequence, the screen cleared for 100 ms before the target word was presented. Target words were lateralized 2.5 degrees of visual angle from the centre of the fixation point to the inner edge of the word (see Figure 6.2). Targets were counterbalanced so that each list contained equal numbers of identity and subset forms of the word. Target words were presented for 150 ms followed by a blank screen. Participants were informed to respond as fast and accurately as possible. After the participant responded, the next sentence prime followed immediately. The computer recorded the accuracy and response time for each target word response. Nine practice trials were conducted before the experimental trials began. The test blocks were separated by one rest break for the approximate five-minute session. In total the experiment lasted approximately 15 minutes.

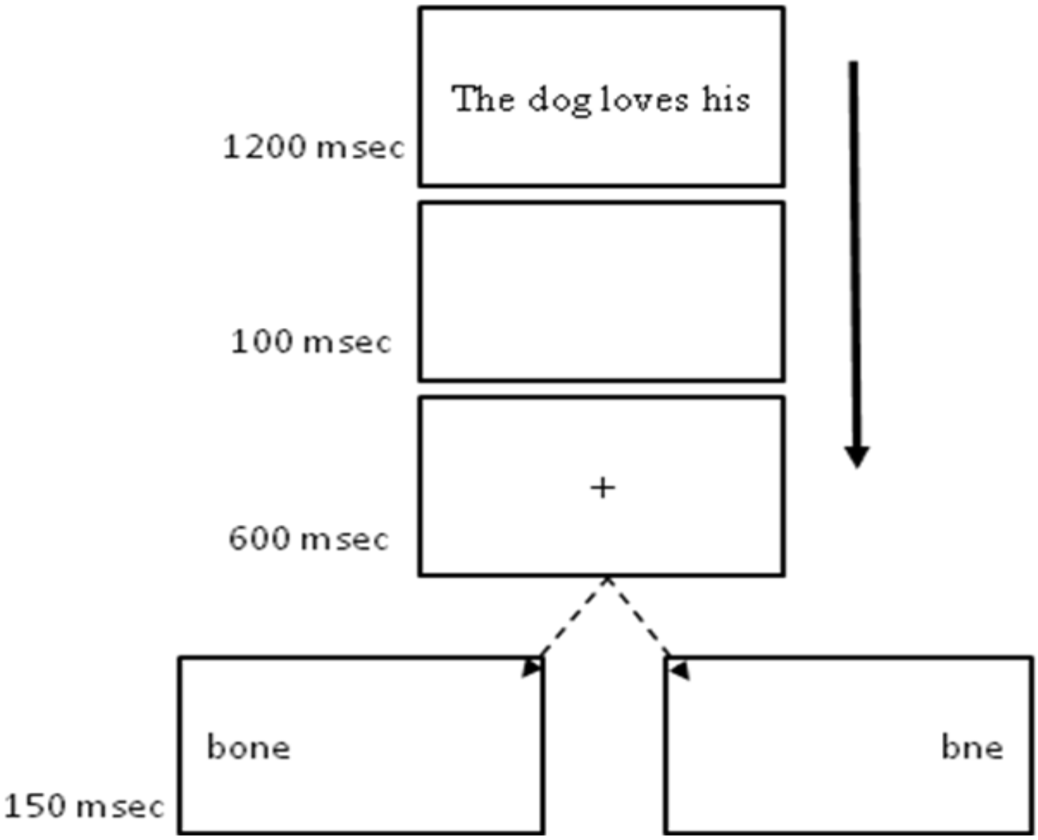

Figure 6.2. Example of stimuli presentation

6.4 Results

Reaction time for "yes" responses. Mean reaction times in ms for "yes" responses were calculated for each participant for both visual fields and both word types. A 2 (visual field: LVF/RH vs. RVF/LH) by 2 x (word type: subset vs. identity) repeated measures ANOVA was employed to test the differences. There was no significant main effect for visual field. There was a significant main effect for word type $F(1,59) = 21.52$, $p < .01$, $\eta^2_p = .27$. When a participant made a "yes" response shown to the left- or right-visual field, they were faster for identity ($M = 897$; $SD = 188.72$) than subset words ($M = 961$; $SD = 244.28$). The interaction between visual field and word type was significant $F(1,59) = 6.34$, $p = .02$, $\eta^2_p = .10$. Participants' "yes" responses were significantly faster when an identity word was shown to the RVF/LH compared to the LVF/RH (see Figure 6.3). We ran two separate pairwise *t*-tests to further explore this interaction. Participants' responses to identity words were faster when shown to the RVF/LH (M = 871; SD = 189.29) compared to the LVF/RH (M = 922; SD =221.10) ($t(59) = 2.38$, $p = .02$, $d = .44$). However, although mean reaction time appeared to differ as a function of visual field/hemisphere presentation for LVF/RH (M = 940; SD = 238.70) and LVF/LH (M = 982; SD = 282.10) for subset words respectively, a t-test failed to show significant differences, $t(59)$ =1.71, $p = .09$, $d = .32$.

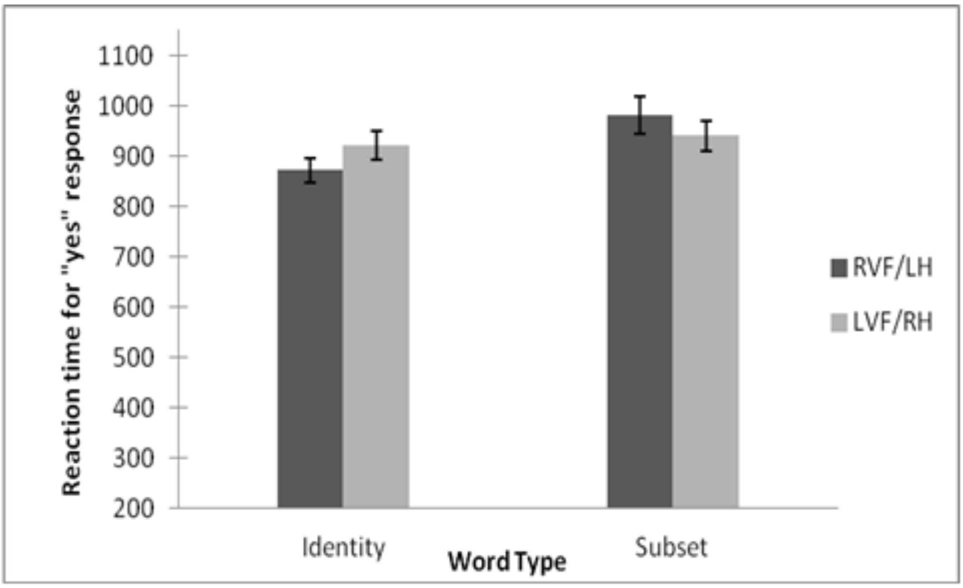

Figure 6.3. Reaction time for yes (match) responses, error bars depict standard error of the mean.

Signal detection analysis. The participants' responses to stimuli shown to the LVF/RH and RVF/LH may have differing discriminability and biases as a function of word type. To further elucidate the impact of identity and subset words on participants' performance relative to visual field/hemisphere presentation, the nonparametric signal detection measures A' and β_D'' were calculated for each participant for each period based on the individual's hit and false alarm rates (see Macmillan & Creelman, 2005). A' was chosen, as the task had blocks with 100% detections and/or 0% false alarms, thus making d' an inappropriate measure of perceptual sensitivity (Macmillan & Creelman, 2005). Discriminability (A') and the bias (β_D'') were calculated based on the proportion of hits (target words judged to make sense with the sentence) and proportion false alarms (non-target words judged incorrectly to make sense with the sentence).

Discriminability (A'). A visual field (LVF/RH vs. RVF/LH) by 2 target word type (subset vs. identity) repeated measures ANOVA for *A′* revealed a main effect of visual field $F(1,59) = 20.71$, $p < .01$, $\eta^2_p = .26$. Participants overall were better able to discriminate between correct/incorrect targets when shown to the LVF/RH. A main effect for word type reached significance $F(1,59) = 5.07$, $p = .03$, $\eta^2_p =.08$. Regardless of visual field presentation, participants' were less able to discriminate subset words ($M = .90$; $SD = 0.07$) compared with identity words ($M = .94$; $SD = .05$) (see Figure 5.4). The interaction between visual field and word type was significant $F(1,59) = 6.93$, $p < .01$, $\eta^2_p = .11$. We performed two pairwise *t*-tests to further explore this interaction. The first *t*-test confirmed that participants' were better able to discriminate subsets words shown to the LVF/RH ($M = .92$; $SD = .05$) relative to RVF/LH ($M = .88$; $SD = .10$) presentation $t(59) = 2.907$, $p < .01$, $d = .60$. The second *t*-test confirmed that there was no statistically significant difference in discriminability of identity words as a function of visual field/hemisphere presentation $t(59) = .249$, $p = .80$, $d = .05$.

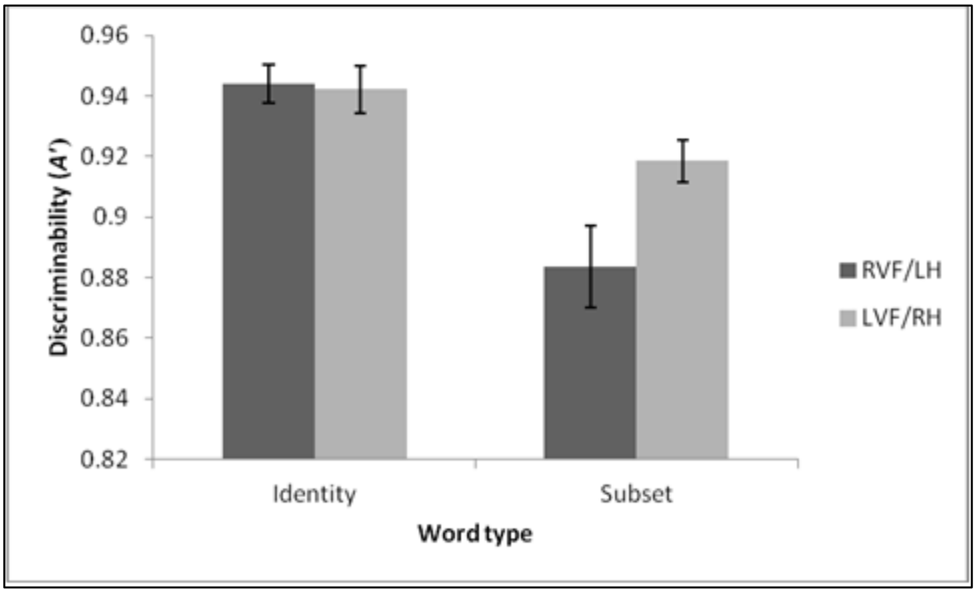

Figure 6.4. Discriminability proportions, error bars depict standard error of the mean.

Bias (β_D''). A 2 (visual field (LVF/RH vs. RVF/LH) by 2 target word type (subset vs. identity) within subjects ANOVA for β_D'' failed to reach significance for either main effect (Fs < 1). There was, however, a significant interaction between visual field and word type $F(1,59) = 21.39, p < .01, \eta^2_p = .27$. When a subset word was presented in the RVF/LH (β_D'' = .210) responses were more conservative, whereas when the subset word was presented in the LVF/RH (β_D'' = -.166) responses were more liberal. Conversely, responses were more conservative to identity words when shown to the LVF/RH (β_D'' = .113) relative to presentation to the RVF/LH (β_D'' = -.192) (see Figure 6.5). We conducted two separate pairwise t-tests to further explore this interaction. The first test confirmed that participants are more liberal to identity words when shown in the RVF/LH versus responding to subset words, $t(59) = 2.99, p < .01, d = .74$. The second t-test confirmed that participants are more liberal with responses when subset words were shown to the LVF/RH compared to identity words, $t(59) = 3.80, p < .01, d = .52$.

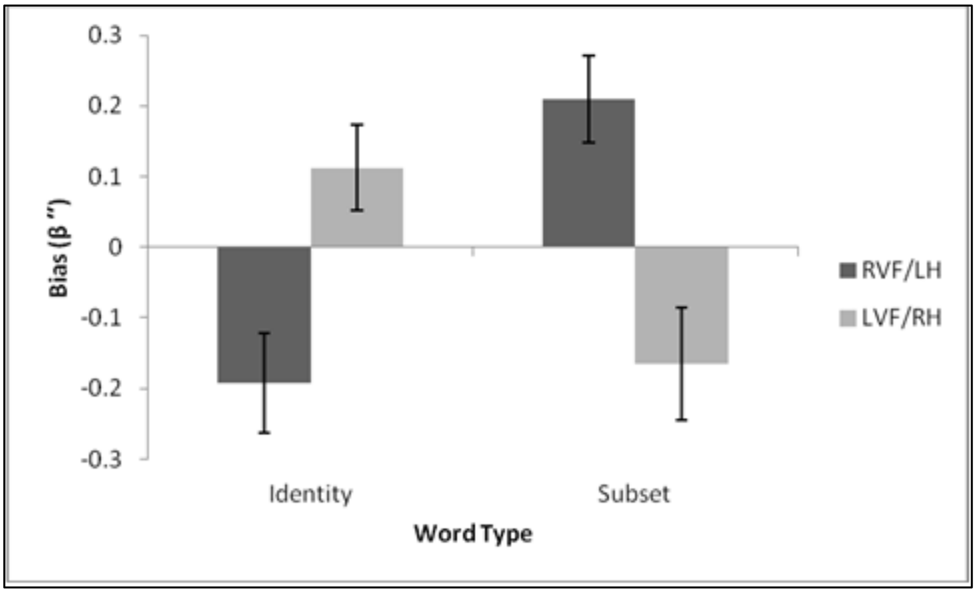

Figure 6.5. *Bias proportions, error bars depict standard error of the mean.*

6.5 Discussion

When the sentence primed readers for a related word, either identity or subset, they responded with faster and more accurate responses to related identity words regardless of visual field. Our results, however, demonstrated that participants were better able to make use of the sentence prime to correctly discriminate subset target words when related to the context of the sentence prime when presented to the LVF/RH compared to presentation to the RVF/LH. In other words, participants were able to correctly judge whether a novel target word made sense with a preceding sentence if shown to the LVF/RH. While decades of research have firmly supported LH dominance for the majority of language processes, it has also been shown that the RH plays a pivotal role in language comprehension. Our data reinforce the latter by indicating that the RH may utilize the context of the sentence more efficiently to mediate the semantic relationship between sentence prime and subset target. In other words, subset words shown to the RH may benefit more from the broader area activation and thus are identified and judged semantically related to sentence context more readily. This finding is consistent with Beeman et al.'s (1994), claims that context has a more prominent role within the RH. Our results indicate the importance of context effects and that cerebral asymmetries may exist for subset processing.

In line with previous research demonstrating RVF/LH facility for language comprehension, participants had a significant response time advantage for identity word stimuli shown in the RVF/LH than when those stimuli were presented in the LVF/RH. However, the visual field presentation did not differ in discriminability for identity words, perhaps due to an overall discriminability ceiling effect for identity words. In both visual fields A' was high for identity words. The unique finding, however, was that participants were better able to utilize related sentence context to support faster (though not statistically significantly so, $p = .09$), more accurate "yes" responses for related subset words when presented to the LVF/RH relative to RVF/LH presentation. Participants were more accurate (higher A') for subset words when presented in the LVF/RH relative to subset word presentation in the RVF/LH.

We argue that the mechanism used by the LH for word recognition is more efficient than the RH for identity words. This would be consistent with Federmeier and Kutas's (2002) theory. The LH may be predictive of identity word stimuli when presented with an associated sentence prime. The RH mechanism in comparison is slower, unpredictive, and may be more reliant on a broader semantic network. Thus, in this study, participants demonstrated a superior processing (correct "yes" detection) of subset words related to the sentence primes when subset target words were shown to the LVF/RH. This advantage may in part be due to subset words requiring broader semantic processing (e.g., an inference regarding subset word meaning given the previously seen sentence prime context). Our results are consistent with previous work that suggests that the RH is better able to utilize activation due to coarse coding (Beeman et al., 2000). As suggested above, we argue that each hemisphere contains differing abilities with respect to language processing and this may indeed result in each hemisphere demonstrating a preference for a particular type of stimuli, identity or subset.

In order to have a better understanding of hemispheric preferences, we implemented the signal detection theory to examine discriminability (A') and biases (β_D''). Contrary to our predictions there was a null effect in A' for identity words between the LH/RH, perhaps, due to a ceiling effect for identity words. We expected participants to have a high A' level for identity words when shown to the RVF/LH due to its advantage in language processing. Conversely, participants were better able to detect subset words when presented to the LVF/RH relative to the RVF/LH presentation. Overall, participants were better at detecting correct match pairs when presented to the LVF/RH versus the RVF/LH. This may reflect the RH's ability to make use of the sentence context to aid in word comprehension, as discussed previously.

Results from the β_D'' analysis revealed differences between the hemispheres. The results supported our predictions with respect to bias of response to stimuli as a function of visual field/hemispheric presentation. Participants were more liberal with responses to subset words as indicated by the negative β_D'' value when shown to the LVF/RH. However, response bias changed completely (positive β_D'' value) when identity words were presented in the LVF/RH. When presented with subset words in the RVF/LH, participants exhibited a positive β_D'' value thus indicating a more conservative response to novel or unfamiliar word stimuli. Conversely, participants presented identity words to the RVF/LH had negative β_D'' bias values. These findings regarding hemispheric differences in response biases match Mashal and Faust's (2008) findings that participants have a more liberal response bias for unfamiliar expressions when presented to the LVF/RH, whereas participants' responses show the opposite response bias when unfamiliar expressions are presented to the RVF/LH.

An alternative, but perhaps not incompatible, explanation for the current results may be based on lateral differences in pattern recognition. The Double Filtering by Frequency (DFF) theory proposed by Robertson and Ivry (2000), for example, builds on a history of studies in which global discrimination of stimuli (low-spatial frequency) have been found to be right hemisphere dominant, whereas, local discrimination of stimuli (high spatial frequency) have been found to be left hemisphere dominant (e.g., Lux et al., 2004; Yamaguchi, Yamagata, & Kobayashi, 2000). While both hemispheres can process a range of frequencies, the hemispheres have a preference or bias for processing low or high spatial frequency information and this bias may generate many of the cerebral asymmetries found in previous studies. Subset-word form recognition from this perspective may be able to take advantage of the pattern-recognition properties of the RH, as the general form of the subset form looks globally similar to the identity form. Indeed if a global word is composed of local graphemes, then missing graphemes from the middle of the word may not substantially alter the global shape. The LH being focused on local elements may be biased for identity forms.

We are, at this point, relatively agnostic regarding the exact rationale for the lateral differences we detect for subset word processing. The results are consistent with a number of proposed theories of cerebral lateralization. We suspect elements of these different theories may indeed be mutually compatible and when integrated will result in a more precise understanding of language processing. We hope research on text-speak may provide a fruitful avenue to explore these issues. From a practical perspective, as mentioned previously in the introduction, digital communication has generated research into better understanding of how individuals process and use text-speak representations. Indeed, Knott et al. (2006) noted that text-speak messages can be generated at a faster rate relative to correctly written out messages. However, this faster rate is at the expense of extra cognitive resources to processes it. We propose one way of curtailing this cognitive resources dilemma and to maximize time, is to change how information is presented to an individual. To reduce cognitive cost one could present a message in a visual field that maximizes hemispheric preference and detection ability for the word type displayed. Thus, message location on a display could be a function of message type (text-speak vs. correctly spelled) to maximize processing and thus free up vital cognitive resources.

On a precautionary note, we acknowledge that this study does possess some limitations. We incorporated a unilateral stimuli presentation which may invoke intentional saccades towards the stimuli (Hunter & Brysbaert, 2008). Bilateral presentation (Boles 1994; Hunter & Brysbaert, 2008) would have been an alternative format. However, to alleviate this concern we implemented standard safeguards. First, we used a flashing central fixation point to draw the participant's attention to the center before target onset (e.g., Kitterle, Christman, & Hellige, 1990; Rapaczynski & Ehrlichman, 1970; Weissmann & Banich, 1999, 2000). Second, we presented targets with equal probability and at random to the left and right visual field to reduce pre-emptive saccades (Bourne, 2006). As prescribed in the laterality literature, we presented targets for 150 ms durations to reduce the likelihood of participant's foveating towards the target word (Bourne, 2006).

Changing how words are presented (e.g., subset form) creates a situation in which different strategies of language processing must be executed and may indicate an increased role for the RH in modern digital language communication such as texting. This RH advantage in texting may be due to the RH's ability to have a broader area of activation and less reliance on correct orthography, thus encompassing the ability to connect distant ideas more readily. This does highlight that the RH is capable of processing novel type language representations and may play a critical role in language processing. Thus an individual given ambiguous or novel word type information may have a greater proficiency in processing it due to the RH being better equipped to handle this type of complicated information. A considerable amount of time and research has been devoted to the understanding of hemispheric differences in processing language. Our findings build on this research by providing a different perspective on hemispheric processing using contemporary word presentation (i.e., text messages). Texting provides a novel communication paradigm that suggests the possibility of a relatively new and increasing role for RH activity in language processing.

Summary and Conclusion. In Chapter 6, hemisphere differences in processing subset and correctly spelled words were investigated using a DVF paradigm. The results revealed that participants had differential performance to subset and correctly spelled target word probes as a function of which visual field/hemisphere was exposed to the probe. Moreover, the response bias results suggest that each hemisphere may be better suited for processing novel word representations or its correctly spelled analogue. In previous chapters it has been established that text-speak is meaningful, albeit less than it's correctly spelled analogue, and requires more cognitive effort to process. As suggested in Chapter 6, gross cortical specificity may exist between the right and left hemisphere of the brain in regards to processing correctly spelled words and text-speak items. To further explore the cognitive cost of processing text-speak and also cortical specificity of the two hemispheres, cerebral oxygenation measurements are taken in Chapter 7 using functional near-infrared spectroscopy. Changes in cerebral oxygenation will be used to index cognitive demand and gross hemispheric involvement when reading text-speak, in comparison with correctly spelled sentences.

CHAPTER 7

Functional Near Infrared Spectroscopy and Text-Speak Processing[7]

7.1 Abstract

As text-based communication increases in the civilian and military workplace (Finomore, et al., 2010) so does the potential to encounter text-speak. It has been proposed that processing text-speak (**I wll tlk 2 u l8tr**, I will talk to you later) comes at a cognitive cost (Head, et al., 2012). To the authors' knowledge, there have been no studies investigating the potential physiological cost of processing text-speak. In the current study we investigate the cognitive cost of processing text-speak by measuring performance on a dual-task while also measuring cerebral oxygenation in the prefrontal cortex. Sixty-four university students completed a dual-task which included a conscious priming task and a vigilance task. Participants also completed a text-speak questionnaire (Head, et al., 2011). The behavioural results failed to show any significant difference in performance between text-speak and correctly spelled text. However, the physiological measurements revealed that the right prefrontal cortex has significantly greater activation when text-speak is shown, thus suggesting a RH compensatory effect. A significant correlation between the text-speak questionnaire and right-hemisphere activation suggests that the right-hemisphere contains the cognitive tools for overriding potential difficulties in processing text-speak.

[7] Paper in press: *Human Factors and Ergonomics*: Head, J., Helton, W. S., Neumann, E., Russell, P. N., & Shears, C. Functional Near Infrared Spectroscopy and Text-Speak Processing.

7.2 Introduction

Text-speak is often word-like and has lexical representation (Head, et al., 2011; Ganushchak, Krott, & Meyer, 2012); however, reading text-speak can be cognitively demanding. Indeed, for those who are literate, word activation is generally automatic and captures attention (Stroop, 1935); conversely, text-speak is not as automatically activated and requires more cognitive effort to process (Ganushchak, Krott, & Meyer, 2010; Head, Russell, Dorahy, Neumann, & Helton, 2011; Perea, Acha, & Carreiras, 2009). This additional cognitive effort may negatively impact performance in military or civilian occupations (Cummings, 2004). Indeed, the increased cognitive effort required to comprehend text-speak may become more pertinent as the use of portable digital messaging devices becomes more widespread in both civilian and the military contexts (Turkoski, 2009; Finomore, et al., 2010).

Head, Helton, Russell, & Neumann (2012) investigated text-speak processing in a dual-task paradigm and found that reading text-speak is cognitively demanding. Participants read a story spelled correctly or composed of text-speak while monitoring and responding to vibrations on the left or right side of their body. Head et al. (2012) found that participants had decreased accuracy and slower responses to vibrations when reading a text-speak story versus a correctly spelled story. Head and colleagues attribute this performance impairment to the cognitive cost that text-speak places on the reader.

As noted previously, text-speak may not be automatically activated and may induce a cognitive cost to the reader. Further support for a cognitive cost when processing text-speak has been noted in eye tracking experiments where it has been found that text-speak items are read at a slower rate, require longer gaze durations, and often have to be reread relative to their correctly spelled analogue (Ganushchak, Krott, Frisson, & Meyer, 2011; Perea, et al., 2009). Collectively, these findings indicate that reading text-speak imposes cognitive loads in excess of those required to comprehend normal text (see Reilly & Radach, 2006; Salvucci, 2001).

To the authors' knowledge, currently there are no published neuro-physiological investigations that explore the additional cognitive load of processing text-speak. In the present study, we wanted to investigate the cognitive cost of processing text-speak by examining vascular hemodynamic differences in the prefrontal cortex. It has been proposed that the prefrontal cortex is active in the allocation of mental resources and is an important component of the central executive system (Jaeggi et al., 2003). Increases in cerebral blood flow to the prefrontal cortex have been proposed to be a function of task demand with increases in vascular activity being a physiological marker of cognitive workload (Jaeggi et al., 2003; Stevenson, Russell, & Helton, 2011; Toronov et al., 2001).

In the present study, we compare hemodynamic differences (i.e., increase in focal cerebral blood flow) in the prefrontal cortex when reading normal text and text-speak to investigate whether text-speak elicits a greater cognitive cost to the reader. In addition, we were interested in whether each hemisphere has differential cerebral activation as a function of sentence type (correctly spelled vs. text-speak). Motivation for this interest comes from a previous study by Head, Shears, Neumann, & Helton, (2013). Head et al. (2013) found that participants responded less accurately and had slower response times when making a "yes" or "no" decision about a text-speak item relative to a correctly spelled word. However, this impairment was modulated by visual field presentation. More specifically, Head et al. found that participants were better able to process text-speak items, compared to correctly spelled words, when these were shown to the left visual field right hemisphere (LVF/RH) and to better process correctly spelled words when they were presented to the right visual field left hemisphere (RVF/LH). Participants were required to read a correctly spelled sentence presented centrally on the screen which was then followed by a briefly (150 ms) presented word probe. Words appeared randomly in the LVF or RVF. Participants made a “yes” or “no” decision on whether the probe word made sense in the context of the previously read sentence. Probe items were either correctly spelled or text-speak abbreviations. Head and colleagues suggested that the RH (LVF) advantage for text-speak occurred because the RH was less reliant on correct spelling, has a preference for processing novel stimuli, and makes more use of sentence context than the LH (RVF).

Unlike Head et al. (2013), we will present sentences composed of text-speak items or correctly spelled words which will precede a correctly spelled word probe. This should maximize participants’ exposure to stimuli, which will yield more concise measurements with the functional near infrared spectroscopy (fNIRS, Rossi et al., 2012). In addition to measuring cerebral oxygenation while participants read correctly spelled or text-speak sentences, we were also interested in the dual-task cost of processing correctly spelled or text-speak sentences. Head et al. (2012) reported a greater cognitive cost on a secondary task when participants read text-speak compared to correctly spelled sentences. To further explore the cognitive cost of processing text-speak, we incorporated an abbreviated verbal vigilance task (Temple et al., 2000) in which participants monitored a rapid sequence of briefly displayed “D” and backwards “D” for an occasional “O”. This verbal vigilance task is cognitively demanding and resource dependent, which is typified by missed targets and slower reaction times on task (Temple et al., 2000). Helton and Russell, (2012) used this task to measure the effects of verbal working memory on vigilance performance. Helton and Russell concluded that verbal working memory load impaired target detection (A') and increased response time with time on task and thus showed that the verbal vigilance task is sensitive to increased working memory demands.

In the current investigation, we examine cerebral oxygenation (i.e., increase in focal cerebral blood flow) in the prefrontal cortex while participants read either text-speak or correctly spelled sentences. More specifically, we want to determine whether there is greater cerebral oxygenation in the RH or LH depending on whether text-speak or correctly spelled sentences are being processed. To accomplish this, we measured cerebral oxygenation using functional near-infrared spectroscopy (fNIRS, Toronov et al., 2001). To further examine the cost of processing text-speak, we will use the abbreviated verbal vigilance task to test whether performance on vigilance is impacted by processing sentences. More specifically, if text-speak is more cognitively demanding to read than correctly spelled sentences, then there should be a greater vigilance decrement on the secondary task and elevated cerebral oxygenation in the hemispheres.

7.3 Method

Participants. Sixty-four New Zealand university students (32 females) provided informed consent to participate in this experiment. All participants were native English speakers with a mean age of 22.8, $SD = 7.32$, right handed, and had normal or corrected-to-normal vision. One participant was omitted and replaced due to a history of acquired brain injury.

Sentence stimuli. The 82 sentence primes (64 experimental and 18 practice) and probe words from Head et al. (2013) were used. For example, a correctly spelled sentence (I will talk to you later) or text-speak sentence (I wll tlk 2 u l8r) were followed by a correctly spelled word probe that made sense in the context of the sentence (e.g., tonight) or did not make sense (e.g., table). Text-speak sentences were created by substituting correctly spelled words with text-speak representations wherever this was possible. On average, 64% of the words in the sentences were replaced with text-speak representations while the remaining 36% were correctly spelled words that comprised predominantly articles and conjunctions (for a similar procedure see Head, et al. 2012). Various shortening techniques were used such as subsetting (dres, **dress**), shortcuts (sk8board, **skateboard**) and numerals (2, **to**) (Chaudhury et al., 2007; Crystal, 2008; Head et al., 2011; Head et al., 2013; Head, Helton et al., 2012; Plester, Wood, & Bell, 2008). Text-speak items were selected when possible from the New Zealand text-speak word norm database (Head et al., 2013). All word probes were correctly spelled and were either related (semantically) or unrelated to the prior sentence. Unrelated words served as filler items for "no" responses. Sentence primes and corresponding related and non-related target words were previously normed on a 5-pt Likert scale (1 = unrelated, 5 = related) (Head et al., 2013). With concern to psycholinguistic characteristics of the stimuli, related sentence primes and their corresponding target words were highly related (M = 4.51, SD = 0.34), while unrelated target words were relatively less (M = 1.5, SD = .94). Target words had an imageability of M = 6.00, SD = 0.94, with a word frequency of M = 3.81, SD = 0.49 (Chiarello, Shears & Lund, 1999). A post hoc analysis did not reveal any relationship between psycholinguistic characteristics of the stimuli and participants behavioral responses. Target words and sentence primes were presented centrally in lower case Courier New 18-point font with correct punctuation.

Vigilance task. The vigilance task consisted of light grey capital letters consisting of an "O", "D", or a backward "D" centered on the video display screen. The letters appeared in 18-point Courier New font and were displayed for 50 ms against a visual mask consisting of unfilled circles on a white background (see Figure 5.1 for an example of the stimulus display). The mask remained visible during a 1,000-ms interstimulus interval so that 1,050 ms elapsed between the onset of displays with an event rate of 57 events per minute. The target "O" had a probability of .12 with neutral stimulus "D" and backwards "D" each having a probability of .44. The circular objects of the mask were 1mm in diameter and were outlined by black lines (0.25 mm thick). Mask elements were separated by 3 mm in the horizontal and vertical directions and by 2.5 mm diagonally. Participants were instructed to respond to the letter “O” and withhold responses to the letter “D” and backwards “D”. Participants were instructed to press the left button of a serial mouse to indicate that the letter *O* appeared. Participants were randomly assigned to one of two conditions whereby the vigilance task occurred before (load) or after (no load) the target probe onset (see Figure 7.1). Participants completed 12 periods of watch which were 1.12 minutes in duration.

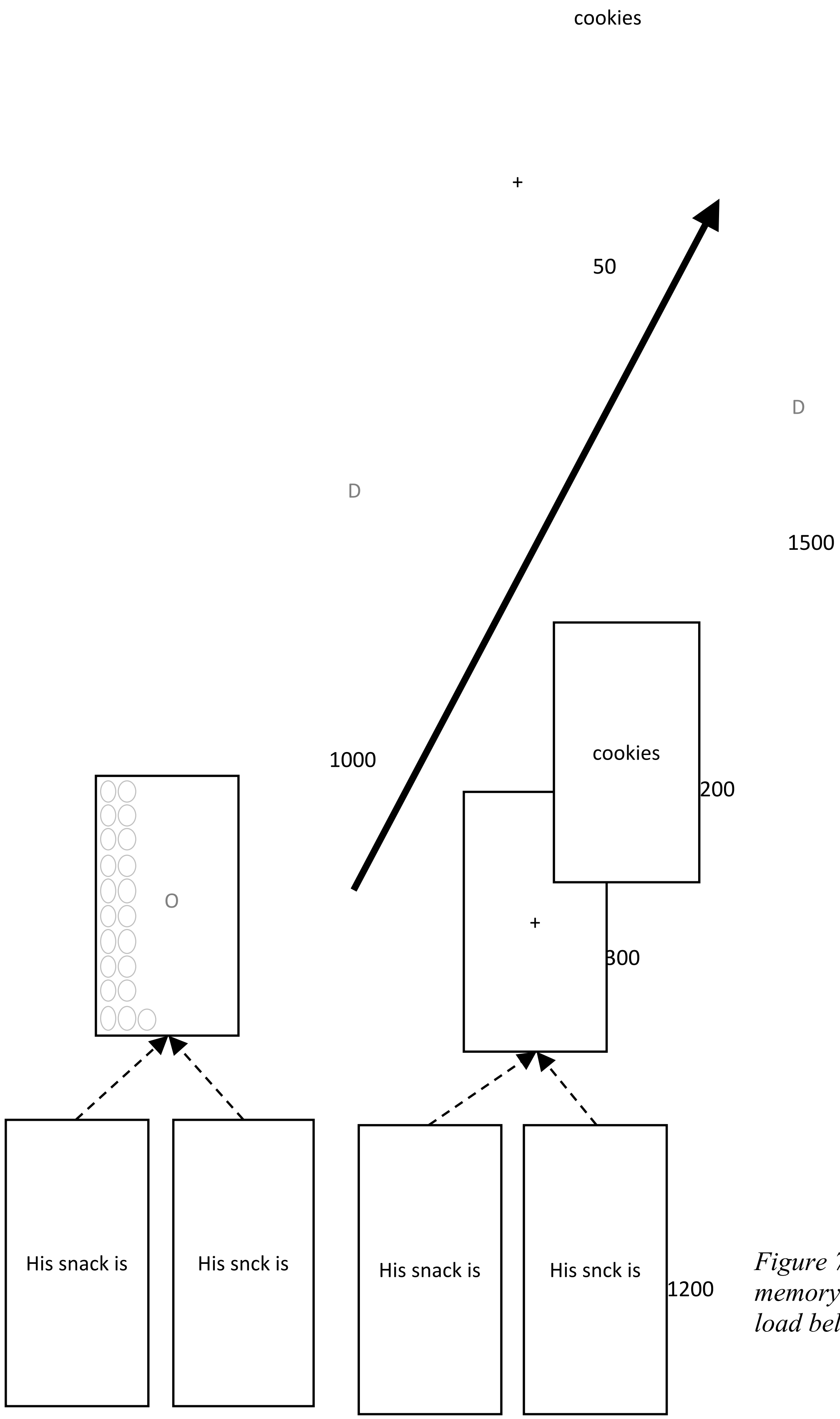

Figure 7.1. Stimuli presentation, memory load above the arrow, no load below the arrow

Functional near infrared spectrometer (fNIRS). fNIRS is a non-evasive and popular technique to measure brain activity within the neuroscience community (Quaresima, Bisconti, Ferrari, 2012). fNIRS uses near infrared light to measure cerebral oxygenation by measuring changes in levels of oxyhemoglobin (O_2Hb) and deoxyhemoglobin (HHb). fNIRS devices are relatively easy to use and can be used in relatively naturalistic settings compared to fMRI (Stevenson, Russell, & Helton, 2011). The main reason for using fNIRS is its ability to measure cerebral oxygenation. Increased cerebral oxygenation has been associated with increases in cognitive demand (Helton et al., 2007; Punwani, Ordidge, Cooper, Amess, & Clemence, 1998; Stevenson, et al., 2011). fNIRS measures "long lasting activation" and thus does not provide focal measurements of rapid neuronal depolarization like EEG and MEG (Rossi, Telkemeyer, Wartenburger, & Obrig, 2012). Therefore, the device is more appropriate for tasks that have longer stimuli exposures and longer task durations

To measure cerebral oxygenation in this task, a Nonin Equanox™ 7600 Near Infrared Cerebral Oximeter (see Figure 7.2) was used. This device has two sensor pads each consisting of two diode lights that emit near infrared light and also two light detectors that receive reflective near infrared light. The frequency of near infrared light allows it to readily pass through the human skull and superficially penetrate into prefrontal cortex tissue (Ekkekakis, 2009). The near infrared light enters the prefrontal cortex tissue at a set frequency and amplitude and is reflected back to the light detectors. The light returning back to the light detectors undergoes changes in frequency and amplitude as a function of the amount O_2Hb and HHb present in the tissue. Due to the differences in molecular makeup of O_2Hb and HHb, both molecules have differences in light absorption characteristics. Therefore, amplitude and frequency of light returning to the light detectors change as a function of the amount of O_2Hb and HHb present in the prefrontal cortex. Once the light returns to the light detectors, the Nonin device calculates the amount of O_2Hb and HHb by taking the known frequency and amplitude of the near infrared light being emitted and compares that to the light being received by the detectors using Beers-Lambert equation[8] which results in numeric coefficients that represent oxygen saturation.

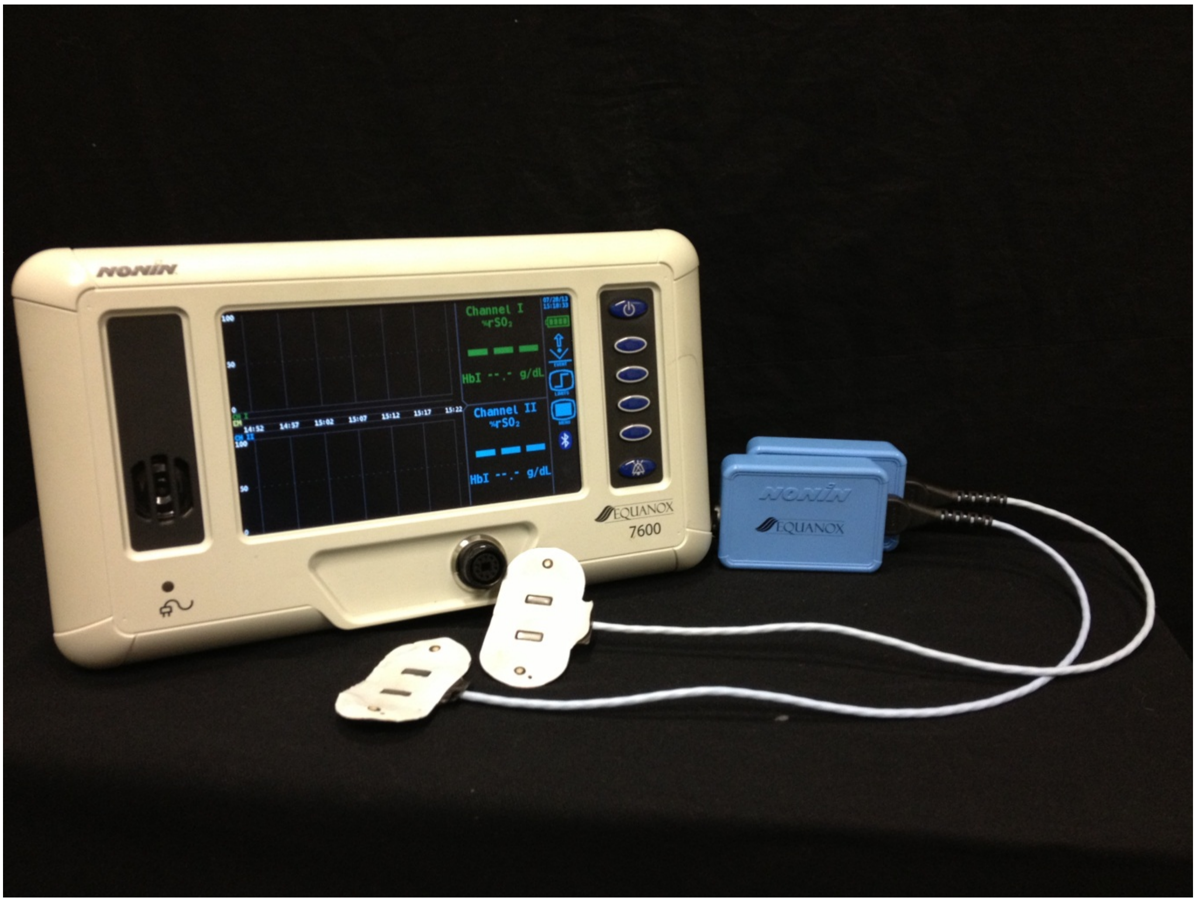

Figure 7.2. The Nonin Equanox^{TM} 7600 Near Infrared Cerebral Oximeter with attached cables and sensor pads

[8] Beers-Lambert equation is based on two separate laws devised by Johann Lamberts and August Beer. Lambert's law states that the absorbance of a material (i.e., molecules) is a function of the thickness of the material (i.e., how far a light source must penetrate through it). The Beer's law maintains that the optical density (material's absorbance) is equal to concentration of the material (Wardle, 2009).

Text-speak questionnaire. The text-speak questionnaire (Head et al., 2011) is a 9-item self-report questionnaire that consists of three factors: Willingness to use text-speak (Factor 1), Preference to use text messaging (Factor 2), and Text messaging experience (Factor 3). This questionnaire has been used in previous studies and has correlated with behavioural measurements (Head, Helton, et al., 2012; Head, Russell, Dorahy, Neumann, & Helton, 2012; Head et al., 2011).

Procedure. Upon arrival, participants were given an overview of the experiment and signed an informed consent form. Participants surrendered cell phones and wristwatches. Participants were seated 50 cm from a 32.5 x 24 cm CRT Compaq S720 monitor at approximately eye level. Participants' heads were not restrained in any way. Participants were told the experiment would test the differences between the left and right hemisphere's processing of language, and that they would be reading sentences and responding to target words. Additionally, participants were instructed that they would complete a secondary vigilance task. Participants were instructed to place equal attention to the reading and vigilance task. They were further instructed to read a sentence and decide whether the target word made sense given the context of the sentence they just read. Participants would then complete a 4.15 second vigilance task before or after the target word presentation. A serial mouse was used to capture participants' responses. For the sentence and target word task, participants were instructed to press the left mouse button with their index finger to indicate "yes" if the target word made sense with the preceding sentence and to press the right mouse button with their middle finger to indicate "no" if the target word did not make sense in the context of the previous sentence read. Sentences and target words were centrally presented in Courier size 18-font with normal capitalization and punctuation. Sentence primes were displayed for 1200 ms. In the no load task, participants were immediately shown a fixation after the sentence. After the fixation period, the target probe would appear for 200 ms followed by a 1,500 ms blank screen. Responses made after the 1,500 ms blank screen were counted as a miss. Responses were measured from target onset. The memory load condition followed the same procedure, with the exception that the fixation period and target word occurred after the vigilance task (see Figure 7.1). Participants completed a practice trial prior to starting the experiment. Upon completion of the practice trial, participants were outfitted with the fNIRS (see Figure 7.3).

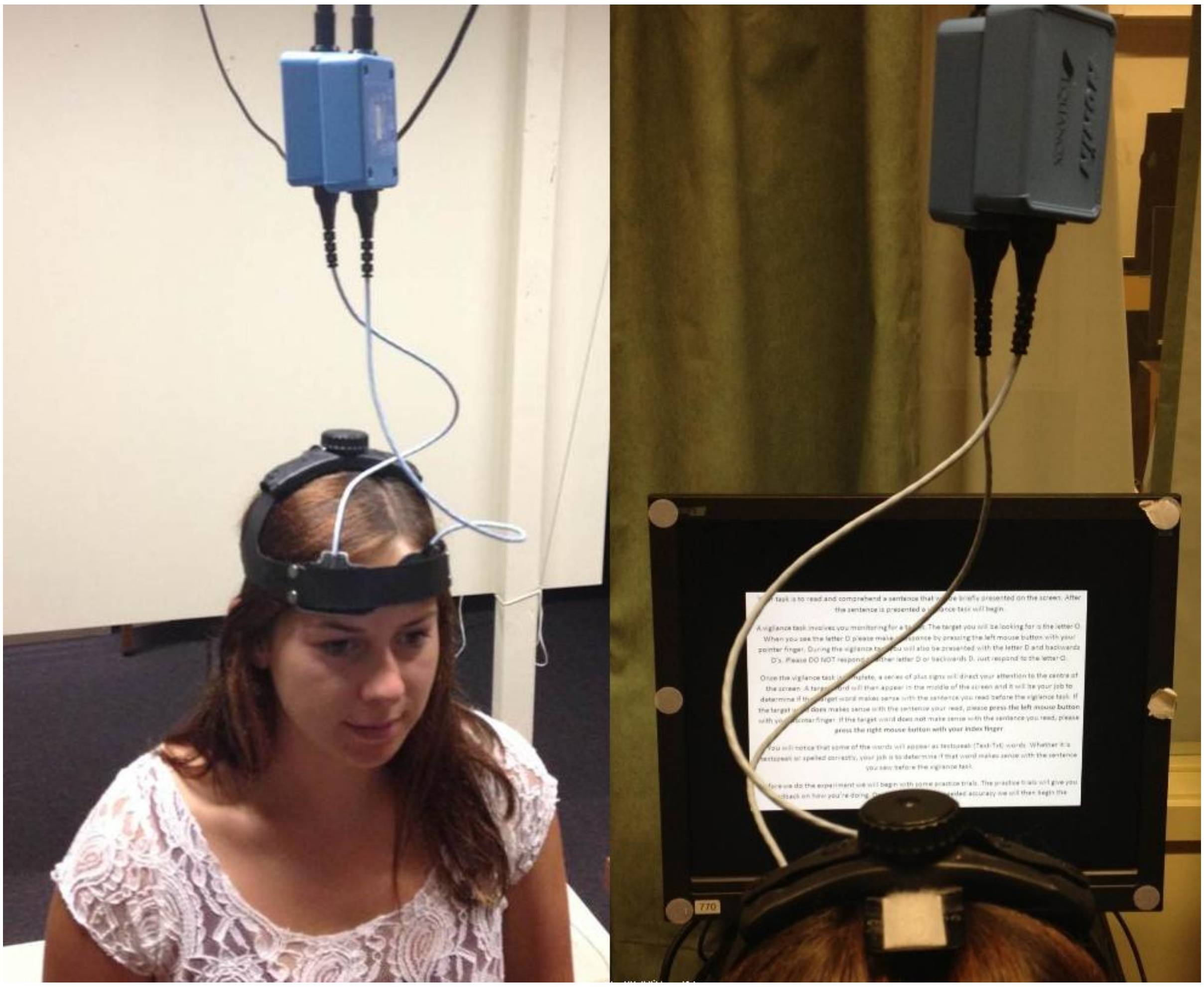

Figure 7.3. Example of participant outfitted with fNIRS leads

Two separate sensors were placed symmetrically on the left and right side of the forehead using the centre of the scull as a point of reference. Special care was taken to avoid hair and the nasal cavity. An adjustable strap was used to secure the sensors to the participant's forehead. Each participant completed a baseline condition whereby they stared at a blank black screen for 5 minutes. Participants were instructed to relax and try not to move (see Ossowski, Malinen, & Helton 2011; Stevenson et al., 2011 for similar procedure). The experimental task began with 4 periods of the vigilance. Participants were instructed that without warning they would begin the secondary task whereby they completed the vigilance task and read sentences and responded to words. Sentences and target words were centrally presented in Courier size 18-font with normal capitalization and punctuation. Sentence primes were displayed for 1200 ms. In the no load task, participants were immediately shown a fixation after the sentence. The fixation consisted of 3 plus signs that alternated in black and red colour (e.g., black/red/black). Each plus sign was shown for 100 ms and gave the perceptual appearance of a flicker to direct participant's attention to where the target probe would appear. After the fixation period, the target probe would appear for 200 ms followed by a 1,500 ms blank screen. Responses made after the 1,500 ms blank screen were counted as miss. Responses were measured from target onset. The memory load condition followed the same procedure, with the exception that the fixation period and target word occurred after the vigilance task (see Figure 7.1). The task took approximately 1 hour to complete.

7.4 Results

Appropriate response times to word probes. Correct median response times were calculated for each participant in their respective condition. Correct responses were subjected to a 2 (sentence type: text-speak vs. correctly spelled) x 2 (memory load: load vs. no load) between-subject ANOVA. No main effects or interactions were significant, $p > .05$.

Correct responses to words. A correct response was defined as a correct "yes" key response to the appropriate sentence and target match. Proportion of correct responses were subjected to a 2 (word type: text-speak vs. correctly spelled) x 2 (memory load: load vs. no load) between-subject ANOVA. No main effects or interactions were significant, $p > .05$.

Target detection sensitivity in the vigilance task. For each period of watch, proportion of hits (correct detections) and false alarms were calculated for each participant. These calculations were used to calculate *A΄* which is a measurement of perceptual sensitivity (Macmillan & Creelman, 2005). *A΄* was chosen due to the abbreviated vigilance task typically having 100% correct hits and/or 0% false alarms, therefore making *d΄* an inappropriate measure of perceptual sensitivity. We employed a 2 (sentence type: text-speak vs. correctly spelled) x 2 (memory load: load vs. no load) x 12 (periods of watch) mixed ANOVA. There was a significant main effect for periods of watch, $F(7.06, 423.83) = 8.33$, $p < .01$, $\eta_p^2 = .12$. Target detection decreased with time on task (see Figure 7.4). All other main effects and interactions were non-significant $p > .05$.

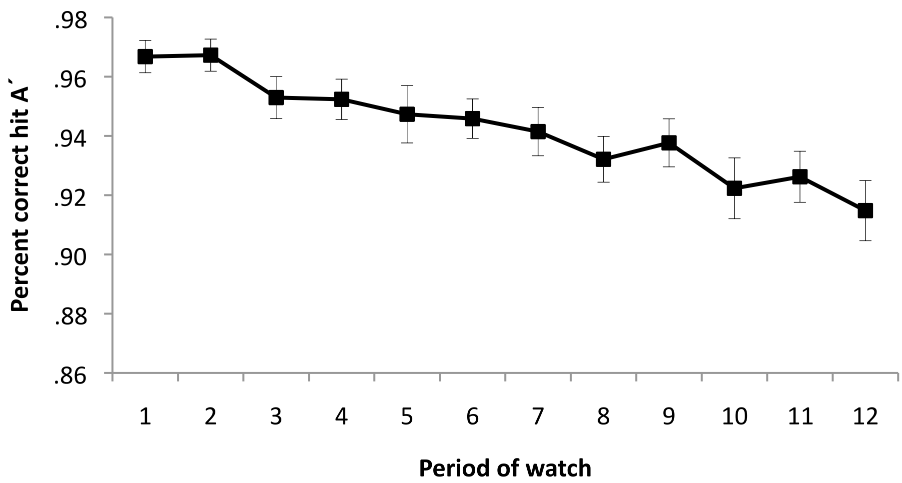

Figure 7.4. *Proportion correct hit, error bars depict standard error of the mean.*
Target detection time in the vigilance task.

For each period of watch we calculated the median response time for each participant. We employed a 2 (sentence type: text-speak vs. correctly spelled) x 2 (memory load: load vs. no load) x 12 (periods of watch) mixed ANOVA. There was a significant main effect for periods of watch, $F(7.25, 435.14) = 9.98$, $p < .01$, $\eta_p^2 = .14$. Reaction time increased with time-on-task (see Figure 7.5). No other main effects or interactions were significant, $p > .05$.

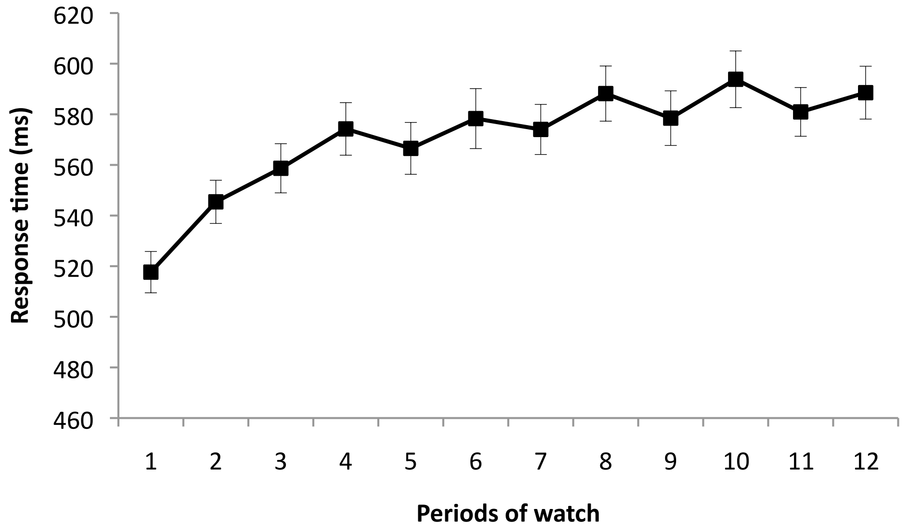

Figure 7.5. Response time for correct response to target, error bars depict standard error of the mean.

Physiology. A relative measure of regional oxygen saturation (rSO_2) was used in this analysis (Stevenson, et al., 2011; Yoshitani, Kawaguchi, Tatsumi, Kitaguchi, & Furuya, 2002). The rSO_2 value was calculated for each hemisphere by taking the difference between resting baseline and the experimental condition. A value of 0 indicates no change from baseline. Each participant's rSO_2 value was analyzed with a 2 (hemisphere: right vs. left) x 2 (sentence type: text-speak vs. correctly spelled) x 2 (memory load: load vs. no load) mixed-ANOVA, which revealed a main effect for hemisphere $F(1,60) = 4.53$, $p = .04$, $\eta_p^2 = .07$, indicating an overall greater increase from baseline for the RH relative to the LH. Crucially, the analysis revealed a significant interaction between word type and hemisphere $F(1,60) = 4.30$, $p = .04$, $\eta_p^2 = .07$. This interaction can be seen in Figure 7.6. No other main effects or interactions were significant, $p > .05$.

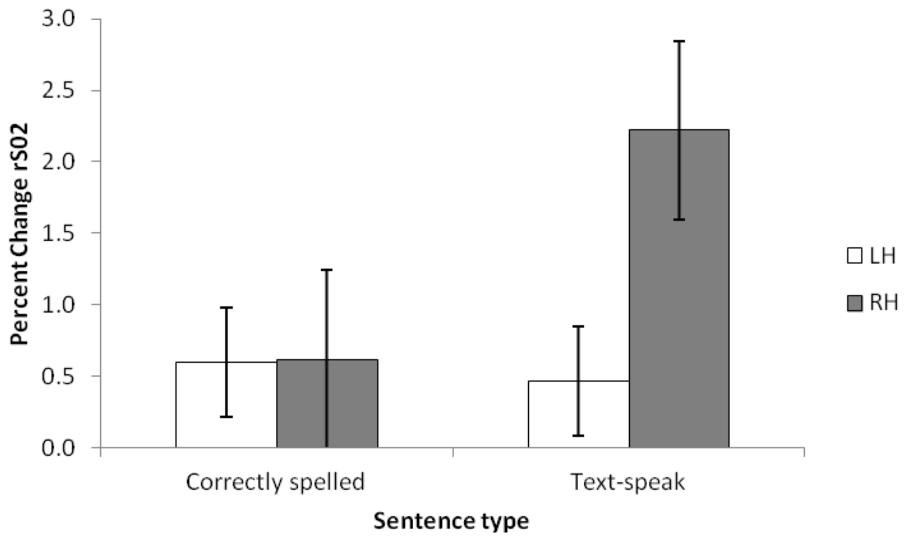

Figure 7.6. Interaction between sentence type and hemisphere, error bars depict standard error of the mean.

Correlation with behavioural metrics. To explore text-speak proficiency with performance we correlated the three factors from Text-speak questionnaire (Head et al., 2011): Willingness to use text-speak, Preference to use text messaging, and Text messaging experience with the behavioural performance of participants (correct responses and response time) and physiological measurements (rSO_2). RH activity was significantly correlated with Factor 1 (r = .248, p = .04). Therefore, as self-reported willingness to use text-speak increased so did the neuronal activity in the RH (see Figure 7.7). No other correlations reached significance.

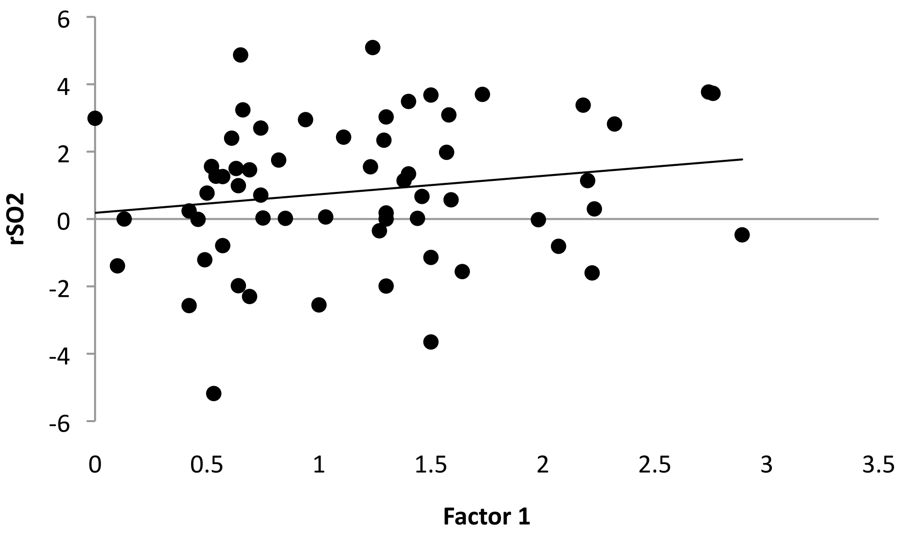

Figure 7.7. Correlation between rSO2 and Factor 1

7.5 Discussion

In the current investigation our main goal was to determine whether the RH and LH produce differential cerebral activation as a function of processing sentences composed of text-speak or correctly spelled words. In addition, we were interested in the dual-task cost of processing text-speak on a secondary vigilance task.

Each participant read sentences composed of text-speak or correctly spelled words while also completing a letter detection vigilance task. Participants made a “yes” or “no” response to whether the word probe made sense with the sentence read beforehand. Participants were randomly assigned to either a memory load or no load condition in which the target word appeared prior (no load) to the vigilance task or after the vigilance task (memory load). In addition, while participants read sentences, we measured cerebral vascular activity in the prefrontal cortex using fNIRS.

Correct responses to whether a correctly spelled word probe made sense with either a text-speak sentence or correctly spelled sentence did not yield any significant differences. With regards to vigilance, vigilance performance decreased with time on task in the letter detection task, but the slope of the decrement was the same regardless of memory load and the type of sentence presentation (correctly spelled vs. text speak). The physiological measurements revealed a significant interaction between word-type and hemisphere. Participants who read text-speak sentences had a greater increase in cerebral oxygenation in the RH. The text-speak questionnaire revealed a relationship between willingness to use text-speak and increases in cerebral oxygenation in the RH only.

Unlike Head et al. (2013), our results failed to show a significant behavioural difference between processing text-speak and correctly spelled content. However, our results did show support for increased RH activity only when shown text-speak stimuli. This increased activity in the RH may signify a compensatory effort in processing text-speak sentences. In other words, it would be similar to the classic speed/accuracy trade-off whereby one sacrifices one performance metric for the other. In this case, in order for participants to have equal performance on processing text-speak and correctly spelled sentences, the RH has to work harder (increase in cerebral oxygenation) to maintain performance. Thus, processing text-speak is at the expense of increased cognitive demand placed on the RH.

Further support for RH involvement in processing text-speak was derived from the positive correlation between Willingness to use text-speak factor and RH oxygenation (rSO^2). This provides support that the RH is more likely to possess the cognitive mechanisms needed to process text-speak and as a consequence has a significant increase in cerebral activation to accommodate the processing of text-speak.

Contrary to Helton and Russell (2012), our results failed to show a relationship between our task and vigilance performance. Moreover, there was no significant difference in vigilance performance between participants reading text-speak versus correctly spelled sentences. These results may in part be due to the stimuli employed in the vigilance task.

Given that only three letters were used in the verbal vigilance task (e.g., "D", backwards "D", and "O") it may have inadvertently become an object feature recognition task, not a verbal working memory task per se. The participants may have been able to perform the vigilance task without using verbal information, thus, reducing the level of interference in working memory. In addition, our primary task, which involved remembering the gist of a sentence, is likely to be less interfering on a perceptual object feature task compared to a verbal task demanding verbatim recall. Indeed, object feature and verbal processing likely involve different areas of the brain and thus would not draw from the same cognitive resources (Head et al., 2012; Wickens, 2002).

Collectively, our results appear to reveal that people process text-speak sentences as readily as correctly spelled sentences, but our results suggest this comes at the cost of greater effort from processes that draw predominantly on the right hemisphere, and presumably the executive system. Moreover, self-reported willingness to use text-speak is associated with RH activation which suggests that the RH may possess the cognitive mechanisms needed to ensure proficient comprehension of text-speak messages.

CHAPTER 8

8.1 Conclusion

The aim of this dissertation was to systematically investigate test-speak in order to contribute and further expand a relatively new and developing research topic. Various methods were used in this dissertation to gain a well-rounded understanding of the types of text-speak created by people. Each chapter of this dissertation is a self-contained study with its own discussion and conclusion. Therefore, I will only briefly reiterate highlights and limitations and discuss future research directions for chapters 2-7 in the paragraphs below.

8.2 The need to assess differences in experience with text-speak.

Prior to this dissertation there was no adequate psychometric tool to measure differences between people in their exposure to and familiarity with text-speak. Therefore, a short text-speak questionnaire was developed with the goal of providing researchers information regarding people's differing experiences with text-speak. Furthermore, no previous investigations have examined whether self-reported experience with text-speak affects their processing of it or brain activity associated with it.

A majority of investigations throughout this dissertation showed relationships between performance on tasks contrasting correctly spelled and text-speak stimuli and experience with text speak as measured by the questionnaire developed in Chapter 2. In Chapter 3, the number of text-messages sent a day showed a relationship with subliminal priming magnitude, thus indicating that those who text-message often are likely more exposed to text-speak items and thus benefit more from subconscious primes. In Chapter 4, the text-speak questionnaire showed a relationship between experiences with text-speak and response time in an attention task. Further, it was able to able to assist in the theoretical interpretation of what the SART measures. In Chapter 5, a dual task paradigm was used to determine whether text-speak impairs performance on a secondary task (vibration detection). Those who reported a greater willingness to use text-speak had better performance on the secondary task while concurrently reading a story presented in text-speak. Finally, one of the most interesting results was the positive correlation between the RH activation and the willingness to use text-speak factor found in Chapter 7. Though not conclusive, this result confirms the finding from Chapter 6 that the RH appears to be more heavily involved processing text-speak messages than correctly spelled sentences.

Collectively, the text-speak questionnaire revealed that greater reported experience with text-speak was associated with enhanced text-speak performance. Additionally, experience with text-speak and performance was not task specific. Text-speak experience showed correlations in unconscious/conscious priming, dual task performance, sustained attention, and blood flow levels in the right frontal cortex. The short and easy to complete text-speak questionnaire has proven to be a valuable tool for exploring several aspects of text-speak processing.

Although short questionnaires are often used with success (e.g., NASA-TLX; Hart & Staveland, 1988), the text-speak questionnaire may benefit from the addition of items that probe other activities with text-speak. The small pool of participants used in the development of the questionnaire may have inadvertently left out key activities where text-speak is used. For example, text-speak has been used in online gaming to allow participants to quickly write each other messages as they compete in game objectives (Chen & Duh, 2007; Iorio, 2007). Thus, potential future questionnaire items involving online gaming should be considered as additions to the text-speak questionnaire.

8.3 Text-speak database and testing whether text-speak it is meaningful

Previous investigations using text-speak as stimuli have relied on a small sample of stimuli that lacked variety. Additionally, stimuli created in past investigations were primarily created by the author, and then validated for comprehension post task by the participants (e.g., Ganushchak et al., 2010). Therefore need for a text-speak database was warranted for future studies on the topic. To address these issues, a text-speak norm database was developed (Chapter 3) and an abridged sample of the items was also empirically tested to determine the extent to which subset words captured the characteristics of full word lexical representations.

Three goals were achieved in Chapter 3. First, a list of text-speak items were created from an established normed word list from Chiarello, Shears, & Lund, (1999). As a result 1,193 text-speak stimulus items were created for future research endeavours. The major advantage of using a previously normed word list was that various psycholinguistic characteristics commonly found in words was controlled for; for example, frequency, parts of speech, and imageability. This resulted in a list of words where researchers could exercise control over the stimuli and decrease the likelihood of third variable confounds. Although the text-speak items created from the previously normed word list permitted better control of psycholinguistic properties of words, it unfortunately also confined participants to use a shortened set of words that they may not commonly use. Additionally, people use a variety of other types of text-speak strategies such as abbreviating phrases (e.g., gtg, go to go). To address this concern, the second goal of Chapter 3 was the collection and cataloguing of text-speak items created by participants. This enabled collection of a larger variety of text-speak items commonly used by participants. The third goal achieved in Chapter 3 was determining whether text-speak items have lexical representation. In Chapter 3 it was revealed that subset text-speak (text, **txt**) items isolated from context of a sentence still contain lexical properties, albeit less than correctly spelled words. The creation of the text-speak database resulted in a large number of text-speak stimuli presently that have been used in six published studies (see chapters: 2, 3, 4, 5, 6, and 7), and will likely be used in future studies investigating text-speak.

Though the creation of a text-speak database successfully addressed the need for normed stimuli for text-speak representations, it may have limitations with respect to its applicability in other English speaking countries. The text-speak items collected were from native English speaking New Zealanders. As pointed out in Chapter 3, the text-speak items used in New Zealand may differ from those used in other countries (e.g., Britain, Canada, and United States) due to regional colloquialism. Support for this comes from preliminary findings from a database I am currently developing in the United States. For example, New Zealanders often shorten words by eliminating the "er" at the end of a word and replacing it with "a", e.g. "banner" is shortened to **bana** in the New Zealand text-speak database. In the US preliminary findings suggest that "banner" is abbreviated as "**banr**". Upon completion of the United States text-speak database, I plan to explore cultural differences between New Zealand and the United States in the construction and use of text-speak abbreviations. Additionally, I would like to assess the impacts on comprehension of reading "foreign" text-speak. Superficially this may appear trivial; however, a small miscommunication between countries could have grave consequences. For example, as modern militaries become more reliant on computer based communication, so does the likelihood of allies communicating with each other digitally on online platforms. If an online message between ally militaries is misinterpreted, it could result in impaired situational awareness which could result in increased friendly-fire occurrences (Salmon, Stanton, Walker, & Green, 2006).

8.4 Text-speak experience and attention

The study of sustained attention (i.e., vigilance) has been extensively researched over the span of six decades dating back to the early 1950's (Mackworth, 1948/1950). As previously discussed in Chapter 4, the ubiquitous findings for vigilance tasks is that as time-on-task increases so does the propensity to miss targets or to correctly respond but with slower response latencies (Head & Helton, 2012; Head, et al., 2011; Helton, et al., 2007; Warm, 1993, 1984). In Chapter 4, a novel approach was taken in two experiments by including text-speak and correctly spelled stimuli as targets and neutral stimuli. The inclusion of these stimuli further expanded the variety of stimuli that could be used in future studies involving the SART and more traditional vigilance task. More importantly, it also permitted the test of two theoretical interpretations of what the SART measures.

As mentioned above, the general findings with vigilance is that as time-on-task increases so does the likelihood of a person making an error (missed target) and target response time. The decline in performance has been noted to occur during the first 30 minutes of a vigilance task (Mackworth, 1948). However, if task demand is significantly increased, vigilance impairment can occur within the first five minutes of the task (Helton, Dember, Warm & Matthews, 2000; Helton, et al., 2007; Temple et al., 2000). Task demand has been manipulated by changing variables such as signal salience, stimulus event rate, and spatial uncertainty all of which have been noted to affect the rate of the vigilance decrement (Davies & Parasuraman, 1982; Warm, Parasuraman, & Matthews, 2008). Prior to this dissertation, however, the use of word stimuli in sustained attention tasks was limited (e.g., Smallwood and colleagues, 2006), and non-existent with text-speak.

The inclusion of correctly spelled words and text-speak items in Experiment 1 and 2 in Chapter 4 provided more complexity and variety to the type of stimuli that could be used in future vigilance studies. Further presenting text-speak items increases task demand relative to their correctly spelled analogues. In both Experiments 1 and 2, performance was significantly impaired in the traditional vigilance task and the SART when participants were required to respond or withhold response (SART) to text-speak targets. These unique findings provide evidence that correctly spelled words and text-speak can fruitfully be used as stimuli in future studies. More specifically, the use of text-speak can allow for further testing of the two theoretical interpretations of the SART (resource and mindlessness theory). Additionally, it provides converging evidence that text-speak imposes greater load on limited cognitive resources.

The actual number of unique stimuli used in the SART and traditional formatted task in Chapter 4 were limited and repeated often throughout the experiment. For example, in the masked priming experiment discussed in Chapter 3 participants responded to 280 different targets with various types of primes. Conversely, in Experiment 1 and 2 in Chapter 4, only two types of targets were used (e.g., txt or text) with only 8 corresponding neutral stimuli for each target respectively. Future studies could use a vastly larger set of stimuli even to the extent that every stimulus was presented only once. For example, participants could monitor for threatening words (e.g., lion, poison, and axe) alternating randomly with neutral words (e.g., chair, wind, and apple), with task difficulty being a function of word frequency.

In addition to providing innovative stimuli for testing sustained attention, two theoretical interpretations of the SART were discussed in Chapter 4, resource theory (Head & Helton, 2012; Helton & Russell, 2011a, 2011b; Helton & Warm, 2008), and Mindlessness theory (Manly et al., 1999; Manly et al., 2004; O'Connell et al., 2006; Robertson et al., 1997). Both theories attempt to explain the underlying cognitive mechanisms responsible for the vigilance decrement. To briefly reiterate, proponents of the Resource theory argue that maintaining vigilance is difficult and demands mental resources. Thus, missed critical targets and slower responses in low Go/ high No-Go tasks are attributed to the depletion of a limited pool of cognitive resources (Helton & Warm, 2008).

Conversely, proponents of the mindlessness theory argue that the vigilance decrement has to do with the repetitive or monotonous nature of the task, which results in participants removing their attention from the task due to the lack of exogenous support (Robertson, et al., 1997). This in part might be true due to the nature of the stimuli generally used in vigilance tasks. For example, stimuli used in visual vigilance tasks have been limited in variety and may lack meaning or interest to a viewer (Head & Helton, 2012). Additionally, the stimuli used in the vigilance tasks often draw only upon a small set of stimuli. For example, the dot flanker task which involves participants monitoring and responding to a rare target dot that is briefly flashed in close proximity to a central fixation amongst numerous distractor dots being presented relatively further from the center. Additionally, vigilance tasks that use the line length task, which involves participants monitoring and responding to a relatively shorter line while ignoring numerous longer distractor lines (for examples see Figure 8.1).

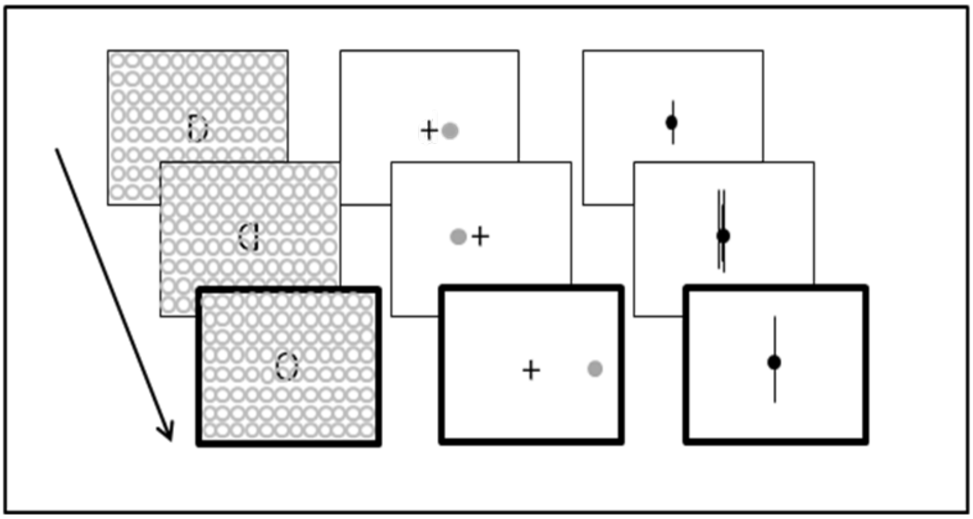

Figure 8.1. From left to right are examples of simple vigilance tasks: alphanumeric task; dot flanker task; line length task. Bolded borders indicates a critical target.

As stated in Chapter 4, those that support the mindlessness theory underpinned their argument based on performance on the SART. Unlike traditional vigilance tasks, the SART is a high Go/low No-Go detection task in which participants respond frequently to neutral stimuli and withhold to targets, with the primary measure of interest being errors as a result of overtly responding to a target. Conversely, those that argue for the resource theory view the SART as a measure of response inhibition with performance being a function of speed-accuracy trade-offs. Thus, proponents of the resource theory argue that errors can be attributed to a feed-forward motor ballistic routine rather than failures in attention. (Helton, et al., 2005).

In Chapter 4, Experiment 1, the inclusion of text-speak stimuli and the text-speak experience questionnaire revealed that performance (response time and accuracy) on the SART to text-speak items can be predicted by the text-speak questionnaire. However, through mediation analysis, it was found that when overall response time was entered into mediation model, experience failed to predict errors to text-speak items. In other words, even with greater exogenous support of attention, experience with text-speak fails to predict performance. Instead, performance was influenced by speed-accuracy trade-offs as purported by resource theorists.

As was discussed above, a relatively larger number of stimuli with greater variety were used in the SART experiment. However, targets and neutral stimuli were repeatedly shown to each participant. Therefore, it is possible that the repeat exposure to the text-speak stimuli may have been perceived as monotonous which masked the influence of experience with text-speak on performance. Additionally, only subset (text, **txt**) text-speak items were used as stimuli. Future investigations should examine the SART using a significantly larger set of stimuli such that target and neutral stimuli are only viewed once and also include a greater variety in the type of text-speak used. For example, using shortcuts (great, **gr8**), numeral shortenings (**2**, to), and emoticons (**<3**, love) with the SART may show a greater influence of text-speak experience may have.

8.5 Cognitive costs of processing text-speak

In Chapter 5, the cognitive cost of processing text-speak was investigated to determine whether text-speak items are more cognitively demanding to process than their correctly spelled analogues. To further explore the resource demands of reading text-speak, a behavioural task was needed that was sensitive to mental workload yet did not interfere with the act of reading. Therefore, a novel dual task paradigm was developed in which participants read a story for comprehension while simultaneously monitoring non-overlapping stimulus modality (tactile vibration) for critical events. Additionally, Wickens' Multiple Resource Theory (Wickens, 1976, 2008) was used to provide a theoretical account of performance impairments caused by reading text-speak.

In the chapters preceding Chapter 5, participants had impaired performance (decreased accuracy and increased response time) when responding to text-speak items. Performance impairments were attributed to the potential cognitive cost that text-speak may place on the reader. A dual task paradigm was chosen to explore the cognitive cost of processing text-speak because dual task situations are considered sensitive to variations in cognitive load (Grier et al., 2008). The results of the dual task revealed that performance impairments are greater on a secondary task when reading and comprehending text-speak prose than correctly spelled sentences. Additionally, the results of the comprehension test revealed a comprehension and performance trade-off. Reading comprehension scores did not differ between reading correctly spelled and text-speak; however, those that read text-speak had greater impairments on the secondary task (i.e., vibration detection task), relative to reading correctly spelled words. This suggests that text-speak is meaningful, but extracting that meaning comes at a greater cognitive cost than comprehending correctly spelled text. To adequately process text-speak, participants must sacrifice secondary task performance to insure comprehension of text-speak content.

The behavioural performance, coupled with the comprehension and performance trade-off, may illustrate the limited mental resource available for processing difficult information. According to the Multiple Resource Theory (Wickens, 1976, 2008), modalities (e.g., visual, auditory, and tactile) each have their own pool of mental resources. Thus, processing two stimuli that arise from different modalities should be less resource demanding than processing both stimuli in the same modality because at the sensory level there is not competition. However, as noted in Chapter 5, reading in general impaired performance on the tactile location task; moreover, reading text-speak caused significantly greater performance impairments. Although the act of reading and monitoring for vibrations are non-overlapping modalities, this multitasking may cause individuals to exceed a threshold or “red-line”. Once this threshold is crossed, performance begins to degrade due to task demand exceeding limited resources. Indeed, as discussed in Chapter 5, reading text-speak further compounds the multitasking demands and thus arguably causes someone to further exceed the “red-line” threshold which could causes even greater performance impairments (Grier et al., 2008).

The dual task paradigm developed in Chapter 5 makes a significant contribution to the current text-speak literature. First, a method was developed that allowed the isolation of processing text-speak versus correctly spelled stimuli and its effect on performance. Secondly, to the author’s knowledge, it is the only study that empirically shows the negative impact of reading text-speak on performance. Thirdly, it provides implications of the possible repercussions of reading while concurrently completing another task. For example, prior to this study, texting was only thought to be dangerous due to the dividing of visual attention between the road and phone and the removal of hand(s) from the steering wheel (Reed &

Green, 1999). The study discussed in Chapter 5 goes further by illustrating the cognitive demand of reading isolated from other visual processing. More importantly, this danger may even be compounded when someone is reading text-speak.

The results from Chapter 5 provide implications of the possible effects of reading while operating a vehicle. However, the experimental paradigm did lack a degree of external validity (Berkowitz & Donnerstein, 1982). Indeed, the literature discussed in Chapter 5 involving dual tasks included the use of driving simulators to mimic reality (Strayer et al., 2003). The use of a driving simulator in future studies with text-speak may have beneficial merits besides achieving ecological validity. As noted in Chapter 5, reading text-speak resulted in more errors and slower response latencies to targets; however, the effect size differences between the conditions where marginal. The marginal differences between text-speak or correctly spelled stimuli may have been due to the low task demands of the dual task. Indeed, driving involves a significant amount of information processing which can be readily manipulated in a simulator (Stinchcombe & Gagnon, 2013). Future studies with text-speak should examine the effects of driving performance while reading text-speak and manipulating task difficulty (e.g., speed of vehicle and road hazards).

8.6 Testing brain asymmetries with processing text-speak

In Chapter 5, neuro-cortical specificity was discussed in terms of different cortical areas of the brain being responsible for processing a specific modality (Head, Helton et al., 2012). In Chapter 6, the idea of neuro-cortical specificity was applied more grossly to the left and right hemisphere of the brain during processing of text-speak and correctly spelled words. To investigate potential laterality effects, a divided visual field paradigm was used to test how people respond to text-speak and correctly spelled target probes when preceded by a sentence prime. Performance (i.e., detection and bias) of target probes was assessed using signal detection theory (Green & Swets, 1974). The results were interpreted in terms of the Coarse Coding (Beeman et al., 1994) and Double Filtering by Frequency theory (Robertson & Ivry, 2000).

In Chapter 6, participants' produced significant differences in performance when responding to correctly spelled and text-speak stimuli as a function of visual field presentation. The signal detection results of participants performance revealed interesting response characteristics as function of target probe type (i.e., text-speak and correctly spelled) and visual field presentation. Participants were better able to detect correctly spelled and text-speak target probes when presented to the RVF/LH and LVF/RH, respectively. Moreover, this same pattern was reflected in response bias. When text-speak items were exposed to the RVF/LH, participants' response bias became more conservative; conversely, when text-speak items were exposed to the LVF/RH, participants' response bias shifted to a liberal response criterion. Differences in bias were also shown when participants were exposed to correctly spelled words. When correctly spelled words were exposed to the RVF/LH, participants' response bias became more liberal; however, participants' response bias shifted to a conservative response criterion when text-speak items were shown.

Prior to Chapter 6 in this dissertation, the role of hemispheric differences in processing text-speak had not been explored. The application of signal detection theory provided a unique way to observe response characteristics of participants as a function of visual field presentation of stimuli. Interestingly, the application of signal detection in divided visual field studies has been rare in past language processing studies. Indeed, prior to the publication included in Chapter 6, to the author's knowledge, there has only been one other study using signal detection theory (Mashal & Faust, 2008) in the study of hemispheric differences. The use of signal detection theory provided support for two theoretical interpretations (Coarse Coding and Double Filtering by Frequency theory) of the results.

Collectively, the two theories suggest a division of labour between hemispheres, whereby each hemisphere may be biased to detect a specific type of stimuli based on the characteristics of the stimuli.

A few limitations in Chapter 6 should be noted. Perhaps the greatest limitation was that only a single variety of text-speak (subset, e.g., **txt,** text) was used. In future investigations it would be interesting to use other forms of text-speak and employ the text-speak questionnaire to examine the role of experience with text-speak. For example, previous chapters have shown correlations between the willingness to use text-speak factor and various measures of text speak performance. It is likely then that those who are more willing to use text-speak items may also have more biases in their decisions when responding to text-speak items.

In addition to including the text-speak questionnaire, a greater variety of text-speak stimuli should be investigated in the divided visual field paradigm. For example, more complex types of text-speak stimuli such as shortcuts (**2nite**, tonight; **gr8**, great) can be included in stimuli sets. Besides increasing the variety of text-speak stimuli, the inclusion of shortcut text-speak would allow for further testing of Double Filtering by Frequency theory proposed in the discussion portion of Chapter 6. As discussed in Chapter 6, the Double Filtering by Frequency theory describes the RH and LH having a bias to process global and local features respectively. Arguably, the inclusion of shortcut type stimuli would result in relatively greater global degraded stimuli features. As a result, it may cause participants to focus on the local features of the “word” and thus cause a shift from RH bias to LH bias when shortcut stimuli are used.

8.7 Neuro cortical specificity and text-speak processing

Throughout this dissertation it has been argued that text-speak is cognitively demanding. In Chapter 5, a dual task paradigm revealed that participants' performance on a secondary task was significantly more impaired when reading a story composed of text-speak relative to correctly spelled words. Cortical specificity was discussed in Chapter 5 with regard to processing different modalities. The principle of cortical specificity was explored grossly with the left and right hemisphere in Chapter 6. A divided visual field paradigm was used in Chapter 6 to examine gross cortical specificity of the left and right hemisphere when processing correctly spelled words and text-speak target probes. Participants revealed significantly better performance when correctly spelled words were presented to the RVF/LH and text-speak target probes were presented to the LVF/RH. Moreover, this same pattern was reflected in participants' response criterion (i.e., bias). Participants' responses were biased to respond to correctly spelled words when shown to the RVF/LH and text-speak items when shown to the LVF/RH. In Chapter 7, fNIRS was used to further investigate the cognitive cost and cortical specificity of processing correctly spelled and text-speak stimuli.

In Chapter 7, participants read text-speak or correctly spelled sentences while responding to correctly spelled target probes. Participants also completed a verbal vigilance task. In addition to the behavioural measurements, cerebral oxygenation of the left and right prefrontal cortex was measured using fNIRS. There were no significant differences in behavioural performance (i.e., accuracy and response time) when reading text-speak or correctly spelled sentences. However, there was a significant interaction between hemisphere oxygenation and word type. The results revealed significantly greater activation in the RH when participants were required to read text-speak. Moreover, there was a significant correlation between Factor 1 (Willingness to use text-speak) and RH activation. The verbal sustained attention task showed the ubiquitous vigilance decrement; however, the task failed to show any interaction with the sentence task. In other words, reading text-speak or correctly spelled words did not have a differential effect on the vigilance decrement.

The use of a physiological measure (fNIRS) provided the advantage of detecting and quantifying changes in mental workload (Brookhuis & De Waard, 1993; Wilson, 2002; Lenneman, Shelley, & Backs, 2005) and thus provided physiological evidence of the cognitive cost of processing of text-speak. Importantly, when participants were shown text-speak stimuli, greater activity in the right prefrontal cortex was observed. The greater activity may suggest cortical specificity when processing text-speak. As noted above, behavioural performance did not significantly differ between reading correctly spelled and text-speak sentences. However, for participants to achieve the same level of performance when reading text-speak, increased involvement of the RH may have been needed to ensure comprehension of text-speak stimuli. This result may suggest a trade-off between comprehension and RH oxygenation to facilitate text-speak interpretation.

In Chapter 5, a similar trade-off pattern was observed between comprehension scores and behavioural performance when reading a story composed of text-speak versus correctly spelled words. Participant's comprehension scores did not significantly differ when reading either text-speak or correctly spelled stories. However, this may be explained by a performance/comprehension trade-off. To reiterate, in order for participants to achieve the same level of comprehension between reading a story presented as correctly spelled or text-speak, participants sacrificed performance on the secondary task (vibration detection) when reading text-speak. As noted above, a similar trade-off may have occurred in Chapter 7. Participants reading text-speak sentences was accompanied by increased RH cerebral oxygenation. In Chapter 7, increased cerebral oxygenation of the RH was argued to reflect additional workload necessary to comprehend text-speak sentences to the same level as their correctly spelled equivalents.

As suggested in Chapter 6, the RH may contain the necessary cognitive mechanisms to process text-speak. Further evidence for RH containing these mechanisms was observed with the correlation between Factor 1 (Willingness to use text-speak) and RH oxygenation. Those who reported a greater willingness to use text-speak also had elevated RH oxygenation. This result may suggest a division of labour between hemispheres for language processing, whereby the RH is recruited when text-speak is shown due to having the utility to process it. As mentioned previously, the elevated cerebral oxygenation in the prefrontal cortex is indicative of mental workload (Jaeggi et al., 2003; Stevenson et al., 2011). Therefore, because the RH contains the utility to process text-speak it exhibits greater cerebral oxygenation reflecting workload placed on it.

Interestingly, the LH failed to show significantly greater cerebral oxygenation when correctly spelled words were shown relative to the RH. Though speculative, the reason for this may be due to the automaticity of reading correctly spelled words (Stroop, 1935). In other words, for a literate individual, reading correctly spelled words is not very mentally demanding on the LH and thus does not require additional mental resources to process it. Perhaps in future studies reading difficulty could be manipulated (e.g., Flesch readability) to see if LH cerebral oxygenation increases as a function of readability difficulty.

In Chapter 7, a secondary verbal vigilance task was used to behaviourally gauge mental workload. Participants were required to monitor and respond to the letter “O” and withhold response to neutral distractors “D” and backwards “D”. This vigilance task was chosen specifically because the stimuli are verbal (letter discrimination). However, choosing this verbal vigilance task may have presented a limitation. It was originally hypothesized that increasing the workload of the main task by presenting text-speak would result in greater performance impairment on the vigilance task because of the cognitive cost of processing text-speak. However, the vigilance decrement was the same regardless of whether people read text-speak or correctly spelled sentences. As pointed out in Chapter 7, there is no certainty that targets were distinguished from targets by their letter names (language processing), the distinction could have been perceptually based (e.g. symmetry, curved vs. straight lines), which would lessen the likelihood of the vigilance task interfering with sentence comprehension.

One way of potentially addressing this limitation noted above would be to use text-speak and correctly spelled words as targets and distractors within the vigilance task as similarly done in Chapter 5. However, unlike the stimuli used in Chapter 5 whereby targets and distractors were recycled (repeated), stimuli could consist of non-repeating stimuli whereby participants respond to targets based on a certain category (e.g., words associated with happiness). The use of non-repeatedly shown word stimuli would prevent participants from using perceptual cues to aid in target selection and thus increase the interference between tasks.

The purpose of this dissertation was to systematically and empirically investigate text-speak processing. As mentioned in the introduction, the format of this dissertation differed from conventional dissertations. It was my goal to disseminate a majority of my work as peer-reviewed publications to make a demonstrable contribution to the literature on text-speak processing. Although this dissertation does not provide definitive conclusion to all the aspects of text-speak processing, it does provide a foundation on which further work can be built on. As a result of this dissertation, a text-speak database was created which not only provided stimuli for various published works included as chapters in this dissertation, but also provides a valuable resource for future investigations of text-speak processing. Collectively, this dissertation provides empirical evidence that processing text-speak is an abundantly meaningful cognitive activity; however, it comes also at a cognitive cost to the readers who process it.

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Appendices

Appendix A
Stimuli and Item Data

Prime	Target	%	RT(SD)
BLSS	bless	56	589(205)
BNE	bone	28	566(158)
DCT	duct	12	702(243)
DFY	defy	20	706(230)
ENGLF	engulf	36	833(373)
OPPSE	oppose	52	613(138)
PD	pad	12	654(203)
PSTER	pester	16	733(260)
RB	rob	12	625(152)
RDEO	rodeo	16	655(231)
RIGR	rigor	32	732(261)
RIPN	ripen	36	738(272)
RLE	role	4	596(181)
RMPLE	rumple	24	734(402)
RNG	ring	56	543(159)
RNK	rink	36	705(313)
ROBT	robot	24	564(140)
RTATE	rotate	16	597(135)
SALD	salad	12	564(160)
SALN	salon	16	623(415)
SALRY	salary	16	600(163)
SAR	sear	4	662(206)
SATRE	satire	4	732(277)
SAUCR	saucer	20	622(274)
SBDUE	subdue	16	771(208)
SCFF	scoff	40	722(225)
SCLD	scold	52	648(265)
SCNE	scene	12	571(162)
SCOP	scoop	16	585(198)
SCRCH	scorch	24	739(355)
SCOT	scoot	4	645(234)
SDA	soda	24	602(156)
SE	sea	4	601(187)
SEIZ	seize	16	657(222)
SERCH	search	40	564(197)
SETTL	settle	20	603(180)
SEVR	sever	40	727(323)
SEWAG	sewage	20	687(231)
SHCK	shock	32	633(310)
SHLF	shelf	56	646(155)

Appendix A
(Continued)

Prime	Target	%	RT(SD)
SHN	shun	8	862(261)
SHRD	shred	40	649(231)
SHRK	shirk	36	655(261)
SHRMP	shrimp	52	626(209)
SKD	skid	36	664(194)
SKM	skim	32	627(197)
SKT	skit	32	694(244)
SLDGE	sludge	28	723(338)
SLG	slug	16	672(238)
SLOCH	slouch	4	635(191)
SLVE	solve	36	629(184)
SMMER	simmer	40	674(254)
SND	send	76	553(116)
SNFF	sniff	60	677(308)
SNG	song	76	546(152)
SNRE	snare	24	623(175)
SNTRY	sentry	48	675(236)
SOCCR	soccer	36	551(123)
SOL	soul	28	613(146)
SONR	sonar	20	785(280)
SOR	soar	32	641(190)
SPCK	speck	28	770(293)
SPHER	sphere	20	650(198)
SPKE	spike	20	598(258)
SPLL	spell	60	551(121)
SPNGE	sponge	48	587(276)
SPRN	spurn	40	799(332)
SQUSH	squash	20	583(264)
ST	sit	4	640(137)
STCK	stack	28	610(175)
STDIO	studio	20	579(172)
STRDE	stride	20	623(260)
STRVE	strive	24	612(202)
STTUS	status	8	603(168)
SUBMT	submit	24	583(172)
SUBRB	suburb	44	643(172)
SUFFR	suffer	24	600(155)
SVE	save	64	614(189)
SWPE	swipe	24	620(171)
SWRD	sword	36	589(208)

Appendix A
(Continued)

Prime	Target	%	RT(SD)
SYRP	syrup	32	644(279)
TANT	taint	12	652(192)
TATTR	tatter	32	733(324)
TCK	tack	4	609(182)
TE	tea	60	563(124)
TECH	teach	32	559(134)
TEETR	teeter	24	807(474)
TEL	tell	64	579(113)
TEM	teem	16	694(409)
TENNT	tenant	36	645(180)
THD	thud	28	718(234)
THGH	thigh	36	582(126)
THME	theme	28	628(227)
THRB	throb	36	646(175)
THRFT	thrift	44	672(294)
TLENT	talent	44	553(101)
TMPO	tempo	36	651(272)
TND	tend	32	557(130)
TNDON	tendon	40	613(244)
TOWR	tower	32	556(111)
TRAT	trait	28	616(159)
TRBE	tribe	20	625(351)
TRDGE	trudge	28	677(225)
TRED	tread	16	626(251)
TRETY	treaty	20	632(370)
TRF	turf	28	683(164)
TRKEY	turkey	20	612(230)
TRPHY	trophy	36	597(174)
TUCH	touch	16	571(209)
TUMR	tumor	28	680(218)
TWN	town	84	613(191)
TYRNT	tyrant	60	688(251)
ULCR	ulcer	12	697(172)
UNFY	unify	8	670(320)
UNT	unit	16	573(134)
UNTE	unite	4	622(173)
VANSH	vanish	24	586(178)
VLUME	volume	32	594(287)
VNE	vine	32	588(202)
VRB	verb	80	584(144)

Appendix A
(Continued)

Prime	Target	%	RT(SD)
VSE	vase	20	622(136)
VTE	vote	4	585(186)
VYAGE	voyage	12	637(200)
WAL	wail	4	734(303)
WANDR	wander	28	708(792)
WDE	wade	8	780(466)
WEGH	weigh	16	612(187)
WELTH	wealth	24	602(211)
WGON	wagon	32	604(191)
WNCE	wince	36	708(372)
WRETH	wreath	20	642(224)
WRK	work	80	605(172)
WRNG	wring	20	743(289)
WRT	wart	20	707(217)
WRTE	write	52	585(150)
WHTE	white	4	702(243)
WSP	wasp	32	630(141)
YLP	yelp	32	712(590)
YUTH	youth	36	558(148)
ZP	zip	4	624(169)
ADHR	adhere	16	750(364)
AGR	agree	24	585(181)
ALLD	allude	52	786(343)
ARG	argue	32	592(150)
AROS	arouse	8	605(168)
ASSM	assume	36	591(152)
AVNG	avenge	36	688(329)
BBLE	bauble	16	771(258)
BCKT	bucket	24	582(115)
BGL	bugle	16	758(235)
BLNG	belong	28	570(151)
BND	bound	20	604(164)
BNNA	banana	24	564(117)
BRD	bride	32	565(113)
BRLY	barley	24	606(151)
BST	beast	4	589(168)
bk	book	4	588(196)
BSTL	bustle	16	645(280)
BTLR	butler	16	657(204)
BTN	baton	20	723(271)

Appendix A (Continued)

Prime	Target	%	RT(SD)
BWAR	beware	36	583(142)
CHM	chime	24	716(256)
CHR	choir	4	611(970)
CHSE	choose	16	581(186)
CLMN	column	48	719(271)
CLSE	clause	12	724(241)
CNCR	cancer	20	575(113)
CNTY	county	8	632(216)
CRK	creek	20	625(201)
CRK	croak	8	699(207)
CVRT	cavort	8	898(374)
CWRD	coward	36	651(208)
CX	coax	4	837(292)
DDCE	deduce	32	678(238)
DETN	detain	40	658(237)
DFFR	differ	32	631(201)
DFND	defend	40	569(172)
DLDE	delude	16	736(328)
DLTE	dilate	12	703(329)
DMN	demon	20	575(128)
DRM	drama	40	607(182)
DRN	drain	16	604(159)
DSGN	design	28	542(141)
DSTL	distil	16	801(365)
DTCH	detach	32	720(259)
DTCT	detect	32	597(167)
DVOT	devote	48	602(197)
DVRT	divert	28	656(315)
DZ	daze	12	662(196)
ENBL	enable	28	599(148)
ENJ	enjoy	28	543(111)
EQP	equip	16	628(148)
ERD	erode	20	683(220)
EXCD	exceed	36	588(125)
FBR	fiber	32	671(234)
FL	fail	4	601(220)
FLCN	falcon	32	620(191)
FLNT	flaunt	24	715(223)
FNDR	fender	24	671(293)
FRD	fraud	16	675(233)

Appendix A
(Continued)

Prime	Target	%	RT(SD)
FRGT	forget	40	563(207)
FT	feat	28	670(344)
FUSN	fusion	8	622(304)
FVR	favor	16	624(277)
GATY	gaiety	12	906(492)
GGE	gouge	8	751(232)
GLLN	gallon	52	672(270)
GLLP	gallop	48	632(196)
GLNC	glance	40	576(152)
GLT	guilt	16	612(166)
GLZ	glaze	32	606(151)
GRD	greed	12	596(138)
GRP	grape	36	610(258)
GRT	greet	8	607(271)
GRVL	grovel	28	652(223)
GUTR	guitar	36	566(108)
GVRN	govern	32	640(223)
HLTH	health	40	527(114)
HNDR	hinder	24	654(284)
HNUR	honour	28	603(164)
HP	hope	64	617(260)
HRSS	harass	44	742(316)
HVN	haven	28	676(248)
IMPR	impair	12	626(24)
INJR	injure	32	666(411)
KDNP	kidnap	24	641(160)
LK	leak	8	620(152)
LNGE	lounge	12	569(156)
LRN	learn	40	556(151)
LSSN	lesson	20	575(202)
LTON	lotion	12	620(147)
MD	mood	8	606(203)
MDFY	modify	20	617(183)
METR	meteor	8	756(343)
MFFL	muffle	28	675(202)
MLDY	melody	12	596(156)
MNC	mince	48	591(168)
MNGE	manage	20	643(193)
MNGL	mingle	16	645(247)
MNR	manor	20	663(224)

Appendix A
(Continued)

Prime	Target	%	RT(SD)
MPRT	impart	32	688(329)
MRGR	merger	24	691(214)
MRN	mourn	36	677(206)
MRSL	morsel	32	676(238)
MRVL	marvel	4	613(150)
MSRY	misery	52	589(141)
MT	meat	4	569(141)
MTHD	method	44	557(137)
NCTR	nectar	28	637(150)
nd	need	4	643(204)
NFR	infer	28	778(313)
NFST	infest	40	609(143)
NT	note	40	560(130)
NTR	enter	48	555(181)
NVRT	invert	40	645(182)
OMLTE	omelette	44	672(210)
PCFY	pacify	8	690(280)
PCH	poach	20	631(184)
PIGN	pigeon	16	593(113)
PLCY	policy	4	588(248)
PLLY	pulley	24	772(299)
PLZ	plaza	28	702(190)
PRCE	pierce	4	685(293)
PRDN	pardon	28	598(163)
PRSN	person	40	540(117)
PRYR	prayer	24	597(162)
PST	paste	48	606(231)
QTA	quota	8	747(313)
RCT	react	4	585(120)
RCTE	recite	12	645(150)
RD	read	28	585(196)
REGN	regain	16	665(422)
RF	reef	8	616(140)
RFNE	refine	16	639(140)
RGN	organ	76	640(249)
REN	reign	12	628(212)
RL	reel	8	681(240)
RVNE	ravine	20	771(250)
STK	steak	20	645(381)
XTND	extend	40	628(287)

Appendix B

#	CS	TS	#	CS	TS	#	CS	TS
1	TEXT	TXT	37	TACK	TAK	73	TOWN	TWN
2	text	txt	38	tack	tak	74	town	twn
3	TeXt	TXt	39	TaCk	TAk	75	ToWn	TWn
4	tExT	txT	40	tAcK	taK	76	tOwN	twN
5	TexT	TxT	41	TacK	TaK	77	TowN	TnW
6	tEXt	tXt	42	tACk	tAk	78	tOWn	tWn
7	TEXT	TXT	43	TACK	TAK	79	TOWN	TWN
8	text	txt	44	tack	tak	80	town	twn
9	TeXt	TXt	45	TaCk	TAk	81	ToWn	TWn
10	tExT	txT	46	tAcK	taK	82	tOwN	twN
11	TexT	TxT	47	TacK	TaK	83	TowN	TnW
12	tEXt	tXt	48	tACk	tAk	84	tOWn	tWn
13	TART	TRT	49	TOWN	TWN	85	TORN	TRN
14	tart	trt	50	town	twn	86	torn	trn
15	TaRt	TRt	51	ToWn	TWn	87	ToRn	TRn
16	tArT	trT	52	tOwN	twN	88	tOrN	trN
17	TarT	TrT	53	TowN	TwN	89	TorN	TrN
18	tARt	tRt	54	tOWn	tWn	90	tORn	tRn
19	TART	TRT	55	TOWN	TWN	91	TORN	TRN
20	tart	trt	56	town	twn	92	torn	trn
21	TaRt	TRt	57	ToWn	TWn	93	ToRn	TRn
22	tArT	trT	58	tOwN	twN	94	tOrN	trN
23	TarT	TrT	59	TowN	TwN	95	TorN	TrN
24	tARt	tRt	60	tOWn	tWn	96	tORn	tRn
25	TOOK	TOK	61	TEST	TST	97	TAPE	TAP
26	took	tok	62	test	tst	98	tape	tap
27	ToOk	TOk	63	TeSt	TSt	99	TaPe	TAp
28	tOoK	toK	64	tEsT	tsT	100	tApE	taP
29	TooK	ToK	65	TesT	TsT	101	TapE	TaP
30	tOOk	tOk	66	tESt	tSt	102	tAPe	tAp
31	TOOK	TOK	67	TEST	TST	103	TAPE	TAP
32	took	tok	68	test	tst	104	tape	tap
33	ToOk	TOk	69	TeSt	TSt	105	TaPe	TAp
34	tOoK	toK	70	tEsT	tsT	106	tApE	taP
35	TooK	ToK	71	TesT	TsT	107	TapE	TaP
36	tOOk	tOk	72	tESt	tSt	108	tAPe	tAp

Notes. CS = Correctly Spelled; TS = Text-speak

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